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SUMMARY AND ANALYSIS OF CONSTRUCTION COSTS OF TEN SOLAR ENERGY SYSTEMS ON COMMERCIAL BUILDINGS

September 30, 1978

U.S. Department of Energy

National Solar Heating and Cooling Demonstration Program

National Solar Data Program

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SUMMARY AND ANALYSIS OF CONSTRUCTION COSTS OF TEN SOLAR ENERGY SYSTEMS ON COMMERCIAL BUILDINGS

Prepared for
DEPARTMENT OF ENERGY
OFFICE OF ASSISTANT SECRETARY
FOR CONSERVATION AND SOLAR APPLICATIONS
NATIONAL SOLAR HEATING AND COOLING DEMONSTRATION PROGRAM

Under Contract Number
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H. Jackson Hale, Solar Data Program Manager

Prepared By
MUELLER ASSOCIATES, INC.

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I. FOREWORD

The National Program for Solar Heating and Cooling of Buildings is being conducted by the Department of Energy as mandated by the Solar Heating and Cooling Demonstration Act of 1974. The overall goal of the federal demonstration program is to assist in the establishment of a viable solar industry and to stimulate its growth. An analysis and synthesis of the information gathered through this program will be disseminated in site-specific reports and summary documents as part of the National Solar Data Program.

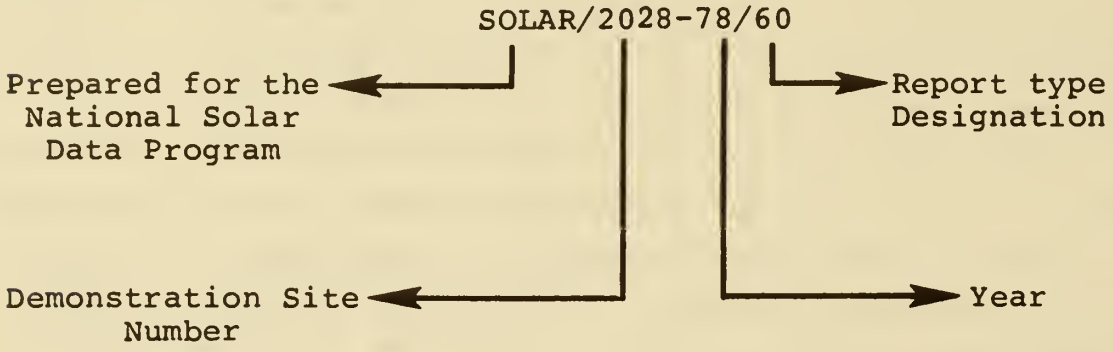
This report presents a summary and analysis of cost data provided in ten Solar Project Cost Reports on commercial buildings. Each report is focused on the construction cost of the solar energy system. No design, start-up, operating or maintenance costs are included, nor are costs included for the solar data acquisition systems (SDAS) and display systems that may be installed in conjunction with the solar energy systems.

Other reports address other aspects of these projects. Detailed understanding of the data presented within this report will require, as a minimum, reference to the "Solar Project Descriptions" for the ten projects that are the subject of this report.

The following are the Report numbers for the subject Solar Project Cost Reports and Solar Project Descriptions:

Project	Solar Project Cost Report	Solar Project Description
Kalwall	Solar/2015-78/60	Solar/2015-78/50
Iris Images	Solar/2005-78/60	Solar/2005-78/50
Hogate's	Solar/2028-78/60	Solar/2028-78/50
Aratex	Solar/2008-78/60	Solar/2008-78/50
Moseley	Solar/2011-78/60	Solar/2011-78/50
Blakedale	Solar/2014-78/60	Solar/2014-78/50
Scattergood	Solar/2003-78/60	Solar/2003-78/50
Radian	Solar/2002-78/60	Solar/2002-78/50
Reedy Creek	Solar/2018-78/60	Solar/2018-78/50
Trinity	Solar/2004-78/60	Solar/2004-78/50

Reports prepared for the National Solar Data Program are numbered under a specific format. For example, the cost report for the Hogate's Restaurant project site is designated as SOLAR/2028-78/60. The elements of this designation are explained in the following illustration:



- Demonstration Site Number:
  Each project site has its own discrete number - 1000 through 1999 for residential sites and 2000 through 2999 for commercial sites.
- Report Type Designation:
  This number identifies the type of report, e.g.,
  - o Monthly Performance Reports are designated by the numbers 01 (for January) through 12 (for December)
  - o Solar Energy System Performance Evaluations are designated by the number 14
  - o Solar Project Descriptions are designated by the number 50
  - o Solar Project Cost Reports are designated by the number 60

These reports are disseminated through the U.S. Department of Energy, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee 37830.

II. EXECUTIVE SUMMARY

As part of the National Solar Data Program, construction cost data for ten operational and instrumented national solar energy demonstration systems on commercial buildings have been collected, analyzed and reported. Cost data were obtained during visits to the sites, discussions with system designers, construction contractors and owners, and by review of DOE vouchers. This report presents a summary and analysis of data contained in ten site-specific Solar Project Cost Reports to identify cost components and the impact of cost factors on construction costs for those ten systems.

An in-depth breakdown of the cost of each solar energy system and an analysis of these costs is provided in this report. Also included is a discussion of the cost data collection methodology. Table II-1 provides project location, construction type and net aperture collector area. The bar chart of Figure II-1 illustrates the total solar energy system costs in terms of dollars per square foot of collector area. Significant variations in the total unit system cost are evident in Figure II-1 and these variations are investigated in this report through an analysis of specific cost categories.

These systems form a small sample size and they were not selected for cost analysis on the basis of their cost representativeness.

The cost figures have been normalized in the following manner:

- No design costs are included.
- No auxiliary system costs are included.
- No instrumentation or display systems costs are included.
- All costs are converted to 1977 dollars.
- A constant overhead and profit has been applied to direct general contractor's costs and subcontractor charges.

Major conclusions of this cost analysis are:

- Very useful cost data can be collected with a reasonable effort when the level of detail requested conforms with standard industry practice.
- Total project construction cost has been obtained in each site studied to date, thus it is reasonable to expect to obtain aggregated cost data.
- The major cost factor determining system cost is system design (specifically, cost/performance trade-offs made by the designer and system complexity).
- Other cost factors that could be identified, but not quantified based on the ten systems studied are:
  - o Physical conditions at the site and building
  - o Aesthetic requirements
  - o Taxes
  - o Size of the project
  - o Geographic area
  - o Contractual instrument

TABLE II-1

PROJECT NAME, APPLICATION, LOCATION, CONSTRUCTION TYPE, AND COLLECTOR AREA

APPLICATION	PROJECT	LOCATION	CONSTRUCTION	COLLECTOR AREA
Passive	• Kalwall Corporation Warehouse	Manchester, NH	Retrofit	1750 Sq. Ft
Process Hot Water	• Iris Images, Inc., Film Laboratory	Mill Valley, CA	New	600 Sq. Ft.
	• Hogate's Restaurant	Washington, DC	Retrofit	5840 Sq. Ft.
	• Aratex Services, Inc. Industrial Laundry	Fresno, CA	Retrofit	6350 Sq. Ft.
Space Heating	• Terrell E. Moseley Office Building	Lynchburg, VA	Retrofit	376 Sq. Ft.
	• Blakedale Professional Center	Greenwood, SC	New	928 Sq. Ft.
	• Scattergood School Recreation Center	West Branch, IA	New	2240 Sq. Ft.
Space Heating and Cooling	• Radian Corporation Office Building	Austin, TX	Retrofit	350 Sq. Ft.
	• Reedy Creek Utilities Co.	Lake Buena Vista, FL	New	3840 Sq. Ft.
	• Trinity University	San Antonio, TX	Retrofit	15633 Sq. Ft.

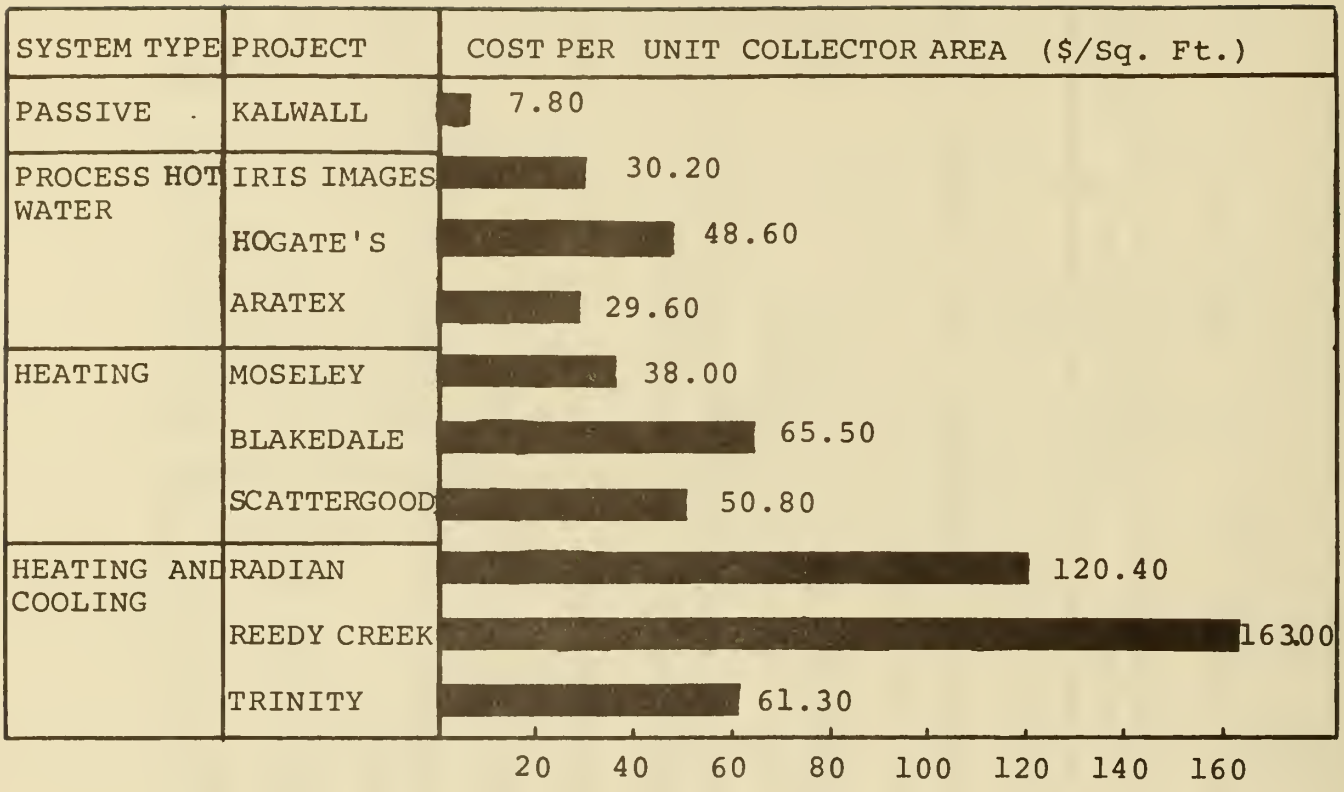


FIGURE II-1

Total System Cost Per Net Collector Area

III. INTRODUCTION

Individual Solar Project Cost Reports were prepared for a variety of commercial projects drawn from the National Solar Demonstration Program. Each report contains a brief project description, an identification of data sources, an analysis of the project construction costs, and a discussion of the special characteristics of each project affecting the reported costs.

In addition to the individual project reports, this summary report is a part of the National Solar Data Program. This report presents comparisons of costs for a variety of systems by cost category and system type. From solar energy project cost information a range of costs for each category can be developed, and through analysis of the available system description and other background information, the impact of various cost factors can be assessed. A very large data base is needed to define completely the range of impacts of all factors. However, trend information should be obtainable through analysis of a sample number of projects.

To date, project cost reports have been completed for the projects listed in Table II-1. This first series of cost evaluations and resultant project reports includes various geographical regions and a wide range of system types, sizes and applications. A reasonable variety of project types and sizes is apparent. All projects evaluated are PON 1 projects, except for Hogate's Restaurant which is a Phase 1 demonstration project.

The comparisons presented in this report are meant to demonstrate the value of the data which will result from detailed cost breakdowns. Potential users of these data should realize that ten sites represent only a limited sample of the demonstration program projects and, as such, are not indicative of all similar projects. Further, for the data to be applied to other solar energy projects it is necessary that the user be sensitive to the special characteristics of individual sites and how those characteristics affect costs. It is essential that the Solar Project Description Documents be consulted whenever attempting to use these cost data.

A third document that the user of these cost reports may find helpful is the Performance Evaluation Report being prepared for a wide variety of projects including those listed here.

The selection of the ten projects for the first cost analysis reports was not based on the cost representativeness of each project but upon the fact that seasonal performance reports had been completed for the studied project. They were operating and generating reportable data. A continuing data reporting effort will provide additional cost reports on other projects on a regular basis.

Among the sites are one passive heating system, three process water/hot water systems, three space heating systems, and three space heating and cooling systems. Six solar systems were retrofit construction, installed after building construction, and four were new construction, installed during building construction. Building use represented includes a warehouse, a film laboratory, a restaurant, a laundry, four office buildings, a gymnasium, and an athletic center/dormitories complex.

Of the active systems, air is the collector fluid medium in one system, antifreeze solution is used in two systems, and water is circulated through the collectors in six systems. Six flat plate and three tracking concentrating collector systems are represented. At two sites collectors were site built, and at seven sites manufactured collector modules were installed. Collector net area ranges from 350 square feet to 15,633 square feet.

Systems are located in New Hampshire, California, District of Columbia, Virginia, South Carolina, Iowa, Texas and Florida.

A major purpose of this analysis is the assessment of the cost data collection approach. Section IV provides a description of and rationale for the methodology used for cost data collection and presents the assessment of that methodology. The systems' costs for the various cost categories are then summarized in tabular form and normalized using several selected parameters.

A discussion follows with a review of cost impacts, and areas for possible cost reduction.

The appendix contains brief system descriptive summaries extracted from the Solar Project Description Documents to provide the reader an overview of the system studied. In addition, some descriptive information on specific subsystems is included in Section V.

IV. METHODOLOGY

A. INTRODUCTION

One purpose of the National Solar Heating and Cooling Demonstration Program is to assess the economic viability of solar heating and cooling systems now and in the future. Accurate data is required concerning the actual construction cost and system performance of these systems coupled with future projections. The demonstration program now consists of approximately 221 commercial projects in various completion stages from design through construction and operation that can provide an extensive cost data base.

Before continuing, two points should be stressed:

- The focus of this work is to collect system construction cost data and not the system operating and/or maintenance costs.
- This discussion is, in general, applicable only to commercial building systems. The data requirements and data collection constraints for the residential building program are different and although related to the commercial sector, require different approaches and treatment.

The remainder of this section will provide insight into cost data collection associated problems, identification of the approach taken by Mueller Associates to collect cost data, and description of the output.

B. DATA USERS

Although many potential uses for solar energy system cost information are obvious, it is useful to list some here to identify the major applications for accurate cost data.

1. DOE Planning and Management

Reliable cost information will permit identification of future demonstration sites that are viable from a cost standpoint.

2. Economic Projections and Analyses

It is generally agreed that the best figure-of-merit for assessing the viability of a solar heating and cooling

system is "Cost/Btu," that is the life-cycle cost of the system divided by the energy provided by the system over its life time. (Life-cycle cost includes initial cost, operating costs and maintenance costs.) An extensive program of instrumented data collection is underway to determine demonstration system performance. To be meaningful, the performance assessment must be accompanied by actual system cost data to obtain Cost/Btu.

3. The Solar Infrastructure

Engineers, architects, manufacturers, and contractors need to know how to estimate solar system costs. Owners need to know what they can expect to spend for a system and what their return on investment will be. Banks need to know what are reasonable costs for system financing purposes. Insurance companies need information to establish appropriate rate structures.

C. CHRONOLOGY OF PROJECT COSTS

A review of the cost figures that evolve during the various phases of a "typical" project is helpful to understand the data collection approach presented here.

1. Preliminary design estimate

The costs presented to DOE by potential grantees in PON submittals are usually based on preliminary engineering estimates related to system conceptual designs. The A/E team will develop a first evolution design and provide the owner with a system construction cost estimate to an accuracy commensurate with the detail to which the design is known. Generally, the designer bases his "guesstimate" upon his experience with similar systems. If he has not had previous solar experience he might use published information. Currently, little credible data is available to most solar energy system designers.

2. Final design estimate

When the owner gives the engineer a notice-to-proceed (subsequent to PON negotiation and award), the A/E team will begin the final design process. At the completion of final design, a final system cost estimate (that is usually obtained from a detailed system take-off) is made. In the case of a solar energy system, the designer with limited solar experience still

must guess at certain unfamiliar aspects of the system, such as collector mounting, collector piping, controls and possibly insulated and buried storage tanks. For conventional HVAC systems and equipment, estimating guides are available, such as "Means" or the "Dodge Manual." These manuals provide detailed materials and labor breakdown for a wide variety of equipment types. In addition, they indicate the types and quantity of labor required for each task. Normally, within the building industry, the final system price (construction cost) must be within ± 10% of the owner's construction budget or the system must be modified to be within that cost range at the designer's expense.

3. Bids from the Contractors

Unless a contract is negotiated with a single construction contractor, a number of construction bids are received from competing contractors based upon the A/E's drawing and specification package. It is not unusual to find significant variations among the bids received. The reasons for the variation are diverse but can include: a "fear factor" applied by contractors unfamiliar with solar energy systems; a contractor who wants solar experience and bids low; contract documents (drawings and specifications) of poor quality that do not define the system well; a subcontractor who does not particularly like working with a specific general contractor (but will work for him if the price is right).

4. Winning contractor's bid

The lowest solar energy system subcontract bidder does not always receive the construction contract. Often selections are based upon the contractor's ability to perform the work and/or his past experience, in addition to the cost. Also, if the solar system is not a large part of the total construction project, the lowest cost for the solar system may not significantly affect the total bid price. For instance, if a very large office building is to be built and it will include a solar energy system whose price is small compared to the total construction price, the general contractor who has the lowest and winning price may

not necessarily have the solar subcontractor with the lowest solar system bid.

It is the winning contractor's price that is perceived to be the "real" cost of the solar energy system. However, for the purposes of estimating future project costs, it is more useful to know the contractor's actual, not bid, construction cost.

5. Contractor's actual costs

To help designers estimate costs, the most valuable information to be obtained from previous projects is how much it actually cost to install prior systems, not how much the installers bid. The bid information is not reliable if the installer lost money, or if he made an excess profit. Thus, it is the contractor's actual labor and materials costs that are available after a project is complete that will be used as the basis for future project cost estimating. Unfortunately, these actual costs are most difficult to obtain. They are rarely recorded in a single source location if they are recorded at all.

D. PAST EFFORTS

Before initiating the data collection process, it was necessary to determine what level of cost information is reasonable to obtain and can be obtained.

Beginning in May, 1977, a series of forms were produced for the collection of data relevant to the National Solar Data Program - directed towards Commercial Demonstration Projects and addressing all information except "instrumented" (Thermal Performance) data. These forms were identified as Series 10, 20, 30, 40 and 50 forms. Because the analytical framework for synthesis and use of these data was only conceptual at that time, it was considered especially important that field data acquisition be started as soon as possible and, in fact, site visits began during May and June, 1977.

Some 15 projects were visited during the May to August, 1977, period. Predictably, the need for changes in the series 10 to 50 data formats was found. Most site physical description

information was available and reasonably accurate, but cost data proved not only hard to find but also more abstruse than had been expected. Fewer than ten percent of the desired cost line items were obtained during the first round of site surveys and cost data that were obtained were of such a nature and variety as to obviate any useful comparative analysis. A revised approach to cost data collection was clearly needed.

Table IV-1 presents the cost breakdown format that was attempted in the Series 20 Data Collection Forms. Five major categories of subsystems were included: collector subsystems, energy transport subsystems, thermal storage subsystems, auxiliary energy subsystems and controls and safety devices subsystems. These subsystems were further broken down into the level of detail shown in Table IV-1. Equipment and materials costs were to be obtained on one set of forms; each item to include component, shipping and total cost. Installation costs were to be obtained on another set of forms; each item to include type of labor, average hourly rate, labor cost for each component's installation, and total cost.

Some of the insights gained through this prior effort are:

- No universal method of cost estimating or cost control is employed in the building construction industry. Some contractors have elaborate computerized systems to track labor and materials costs; others keep invoices in loose files and maintain few records of labor requirements.
- In retrospect, most past efforts at cost data collection have sought excessively detailed information that is not generally available for a building project.
- Many different types of organizations and contractural instruments are in-place in the Program and each type has unique considerations with respect to organization capabilities, experience and inclination to collect the types of cost data sought. Some organizations that have been awarded contracts act as the general contractor for construction while others hire a general contractor.

TABLE IV-1

COST BREAKDOWN FROM PREVIOUS

SERIES 20 DATA COLLECTION FORM

COLLECTOR SUBSYSTEM	AUXILIARY ENERGY SUBSYSTEMS
Collectors Mounting Frame Reflector Ducting & Piping Dessicant	Furnace/Boiler Resistance Heater Hot Water Heater Heat Pump Air Conditioner Dehumidification
ENERGY TRANSPORT SYSTEM	CONTROLS AND SAFETY DEVICES SUBSYSTEM
Transfer fluid Piping/Manifold (Ducting) Pumps (Blowers) Valves (Dampers) Filters Insulation Heat Exchangers	Sensors Actuating Devices Pressure Regulators Temperature Regulators Subsystem Fail-Safe Controls Load Supply Mode Selector Unit Collector/Storage Flow Control Selector Unit Tracking Mount Drive Control Unit
THERMAL STORAGE SUBSYSTEM	MISCELLANEOUS EQUIPMENT AND MATERIALS
Storage Medium Tank/Container Filters Insulation Container Lining Exterior Finish Racks & Troughs for Latent Heat Storage Materials Auxiliary Heaters	Electrical Wiring Other

A single approach to cost data collection is difficult to apply to every project studied.

- Different constraints to cost data collection resulting in various quality levels apply to projects in construction, completed projects and projects still in planning and/or design.

E. PRESENT APPROACH

The revised approach to disaggregating data into solar system cost categories for every installation is to resolve the data into elements at two levels of detail, primary and secondary. Table IV-2 shows the level of disaggregation associated with the primary and secondary cost breakdowns.

In general, the primary cost categories follow work categories typically performed by different trades or subcontractors on building systems construction projects, and these are expected to be separable, identifiable costs. The secondary cost categories represent a more detailed breakdown of the primary categories and are more difficult to obtain. In general, this information is sought through discussions with subcontractors and other project personnel, and by reviewing project records.

The secondary breakdown stops short of obtaining information on individual components, except for the collector and possibly heating and cooling equipment. The reasons for this are that information on non-solar specific components such as pumps and valves are available elsewhere and most contractors do not maintain labor records to that level of detail.

The following are typical examples of components comprising the cost breakdown categories listed on Table IV-2:

- Collector Array: all materials provided by collector manufacturer (including tracking mechanisms, attachment fittings, hoses), labor to install collectors on support structure, labor and materials to connect collectors to supply and return manifolds, and miscellaneous specialities required for a complete array.

- Collector Support Structure: all framing, beams and columns, roof connections, fasteners and brackets required to receive collectors.
- Piping: all collector distribution and major supply and return piping, external collector manifolds, if required, pumps, expansion tanks, valves, interconnecting piping, hangers and miscellaneous piping specialties.
- Ductwork: all ductwork connecting collectors to air handling equipment, dampers, interconnection with auxiliary systems and filter boxes.
- Insulation: all insulation - both interior and exterior - for piping and ductwork, chillers, and miscellaneous equipment, except energy storage containers.
- Heating/Cooling Equipment: absorption chillers, heat pumps, air handling units or heat exchangers used to interface with auxiliary system or to deliver energy directly to load.
- Storage: vessel or container, lining, supports, pads, internal piping, nozzles, and insulation.
- Controls: solid state controllers, thermostats, alarms switches, wiring, automatic valves and miscellaneous pneumatic or electrical devices.
- Electrical: normally an identifiable subcontract including power wiring, motor controllers, starters, conduits, disconnect switches, and miscellaneous high voltage electrical devices.
- General Construction: excavation, crane, tool and equipment rental, permits, painting, architectural modifications or additional space requirements, roofing and temporary services such as clean-up, field offices, and temporary telephone and electrical service.

Auxiliary energy system costs are not included as part of the solar energy system costs.

In all cases, obtaining accurate total project cost is the primary goal of data collection.

Site visits were made to obtain cost data. General contractors are the focus of data collection since they are

TABLE IV-2

SITE SPECIFIC COST BREAKDOWN

PRIMARY	SECONDARY
Collector Support Structure	• Materials • Labor
Collector Array	• Materials • Delivery • Mounting on Support Structure • Connecting Collectors to Manifold
Piping System	• Collector Distribution System o Materials o Labor • Other Piping o Materials o Labor
Ductwork	• Collector Distribution System o Materials o Labor • Other Ductwork o Materials o Labor
Insulation	• Collector Distribution System o Materials o Labor
Heating/Cooling Equipment	• Materials • Delivery
Storage	• Materials • Delivery • Installation • Insulation
Controls	• Materials • Labor
Electrical	
General Construction	• Roofing • Equipment Room • Architectural • Excavation • Painting
TOTAL PROJECT COST	

usually able to provide the most cost information for each project and at a credible level. However, where possible each major subcontractor was interviewed to obtain more specific information pertaining to respective subsystems. Personnel from the contracting firms who were actually on site performing the work and those who kept the cost records were interviewed when possible.

For each cost category the following types of information are sought:

- o Labor type utilized
- o Number of workers utilized
- o Number of hours required
- o Time per unit of equipment installed
- o Materials cost
- o Labor rates
- o Delivery costs of major items
- o Overhead factors
- o Total costs

This information is obtained from cost files, invoices, time logs, government payment request vouchers, monthly progress reports, bills-of-materials, and in-person interviews.

In addition to the above data, each contractor and subcontractor is questioned concerning observed areas for cost reduction and cost estimating employed to date. Engineers, architects and building owners are interviewed to obtain preliminary and final engineering cost estimates, range of bids received and any other pertinent cost information.

F. RESULTS

Figure IV-1 illustrates the success rate of the cost data collection process for the ten sites for the primary cost categories. For each of the primary cost categories it shows the percentage of the total number of applicable sites for which that category cost could be separated. It must be remembered that even though a category cost could not be separated, the <u>total</u> system cost is accurate.

Figure IV-2 illustrates the success rate for obtaining the secondary cost categories data for applicable sites.

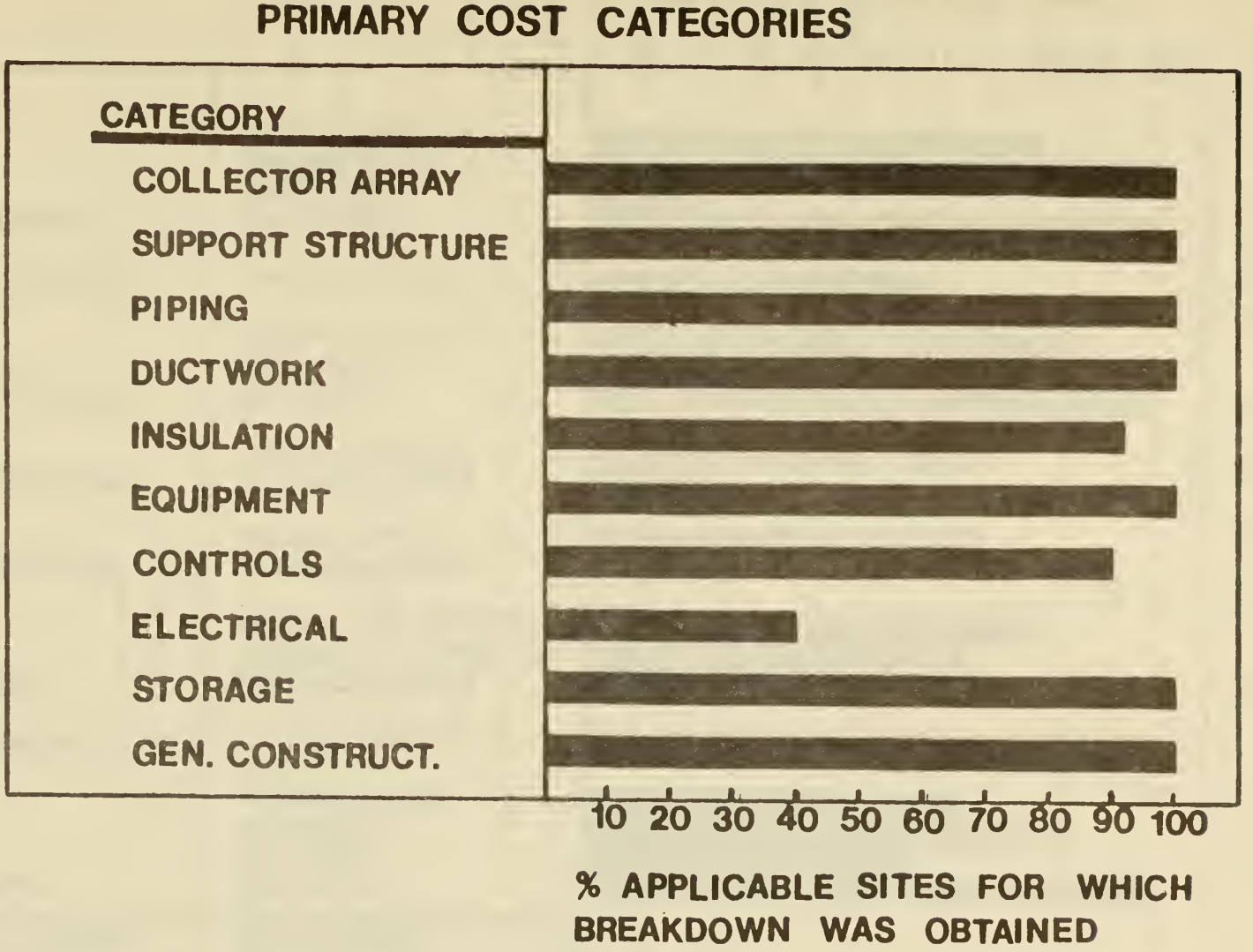


FIGURE IV-1 Success Rate for Primary Cost Categories

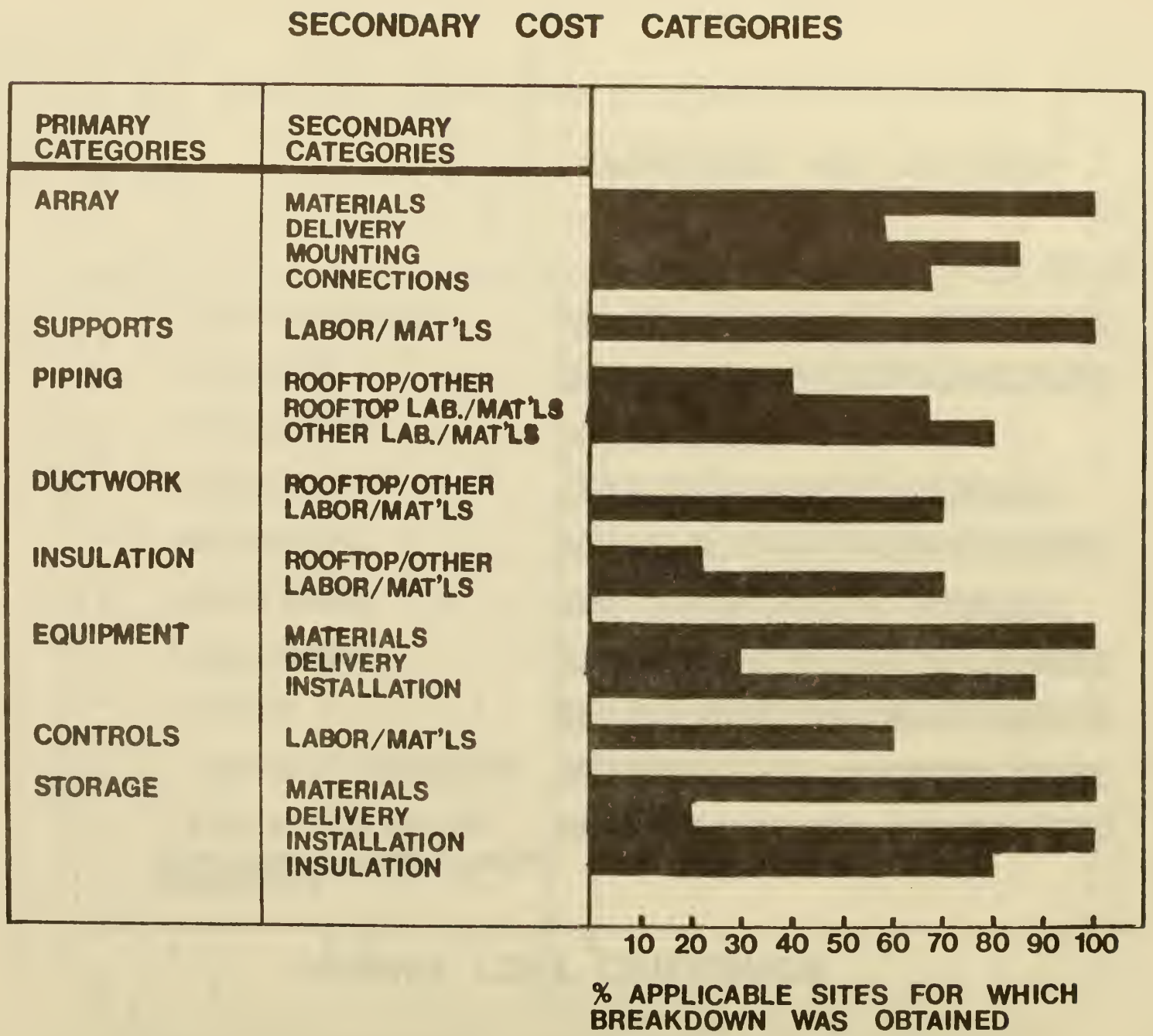


FIGURE IV-2 Success Rate for Secondary Cost Categories

The percentages for each category are based on the total number of projects which should have data in that category. For instance, many projects had no ductwork and these projects are not included in the total number on which the percentage presented for the ductwork category is based.

Of the primary categories only the insulation, control and electrical categories could not be separated at all sites. Figure IV-2 indicate that the secondary categories represented, in general, a reasonable level of detail to attempt to obtain. Most category data were obtained for a significant percentage of the sites. Some category data, like the piping in the collector distribution system, were obtained relatively few times. This is because the breakdown did not follow industry standard categories of labor type and so were not "natural" information for the Contractor to keep.

An analysis of Figure IV-2 indicates that a level of detail greater than that sought could not be obtained reliably.

More detailed information than the secondary breakdown is sometimes presented in the cost reports if it was available and appeared to be of interest. For instance, if the total cost of the pumps in a project is known, or if the total cost of the automatic valves is known, those costs are reported.

The level of detail of cost data that can be obtained from a project is limited. However, very useful data can be collected with a reasonable effort when the level of detail requested conforms with standard industry practice. Not all data points requested will be separately identified at each site. Nonetheless, when more sites have been reviewed adequate data should be available for each item for the intended uses of the data. The <u>total</u> project construction cost has been obtainable in each site studied to date.

V. SUBSYSTEM COST ANALYSIS

Cost data for the ten systems are presented in this section. The data are broken down into the cost categories described in Chapter IV. The comparisons drawn in this report are meant to demonstrate the value of data resulting from detailed cost breakdowns. Potential users of these data should realize that ten sites represent only a very limited sample size from the demonstration program and, as such, are not necessarily indicative of all similar projects. Further, for the data to be useable it is necessary to be sensitive to the special characteristics of individual sites and how those characteristics affect costs. The Solar Project Description Documents should be consulted whenever attempting to use these cost data. Many figures in this Report are taken from the referenced description documents.

In order to make comparison of costs between systems more meaningful, the cost figures have been normalized in the following manner:

- These data do not include any costs associated with the design work.
- The costs of auxiliary hot water, heating, and/or cooling components are not included.
- The costs of the instrumentation and data acquisition system used to measure system performance are not included.
- All costs are converted to 1977 dollars using the construction cost inflation rates published in the Engineering News Record.
- The data collected represent cost to the general contractor. Meaningful total costs should include contractor's overhead and profit factor (OH&P). OH&P factors vary according to the type of organization that is contracted. A standard OH&P factor of 25% is added to all direct costs to the contractor, and an OH&P factor of 10% is added to subcontract costs. The subcontractors' overhead and profit could not be removed in most cases.

- The costs presented in many places in this report are often based on cost per unit of collector aperture area ($/Sq.Ft.) associated with the project or in terms of percent of the total system cost. It is recognized that these conventions are only meaningful when comparing systems of similar performance, construction aspects, and building type on relative terms. The cost per unit energy output of the system would be a much more complete and uniform economic evaluation parameter. Still, $/Sq.Ft. and percent total system cost are useful for cost analysis when their limitations are kept in mind.
- In some categories, cost is also reported in relation to an index other than collector area. For example, controls subsystem cost is provided as cost per controlled motor as well as cost per unit collector area.

The cost data in this section are presented in Tables V-1 through V-15. The following points should be remembered when using the tables. The projects are grouped in the tables into four types; passive, process hot water, space heating, and space heating and cooling projects. See Table II-1 for a quick overview of project types.

"Bare Costs as Reported" indicates that the costs do not include overhead and profit and they are listed in unadjusted dollar values as recorded and reported for the year the systems were built.

The label "1977 $'s" heads columns that have been adjusted to 1977 dollars through use of the construction cost index. All projects studied were constructed in either 1976 or 1977. A factor of 7.4% was added to 1976 costs.

"General (G) or Sub (S)" indicates whether the costs were incurred by the general contractor or one of his subcontractors. If both are given, most of the costs were incurred by the first listed and the remainder was incurred in the amount and by the person in parenthesis.

"W/OH&P" means that the general contractor's overhead and profit is included.

"Percent of Total Cost" means the percentage of the total system cost that is represented by that particular category.

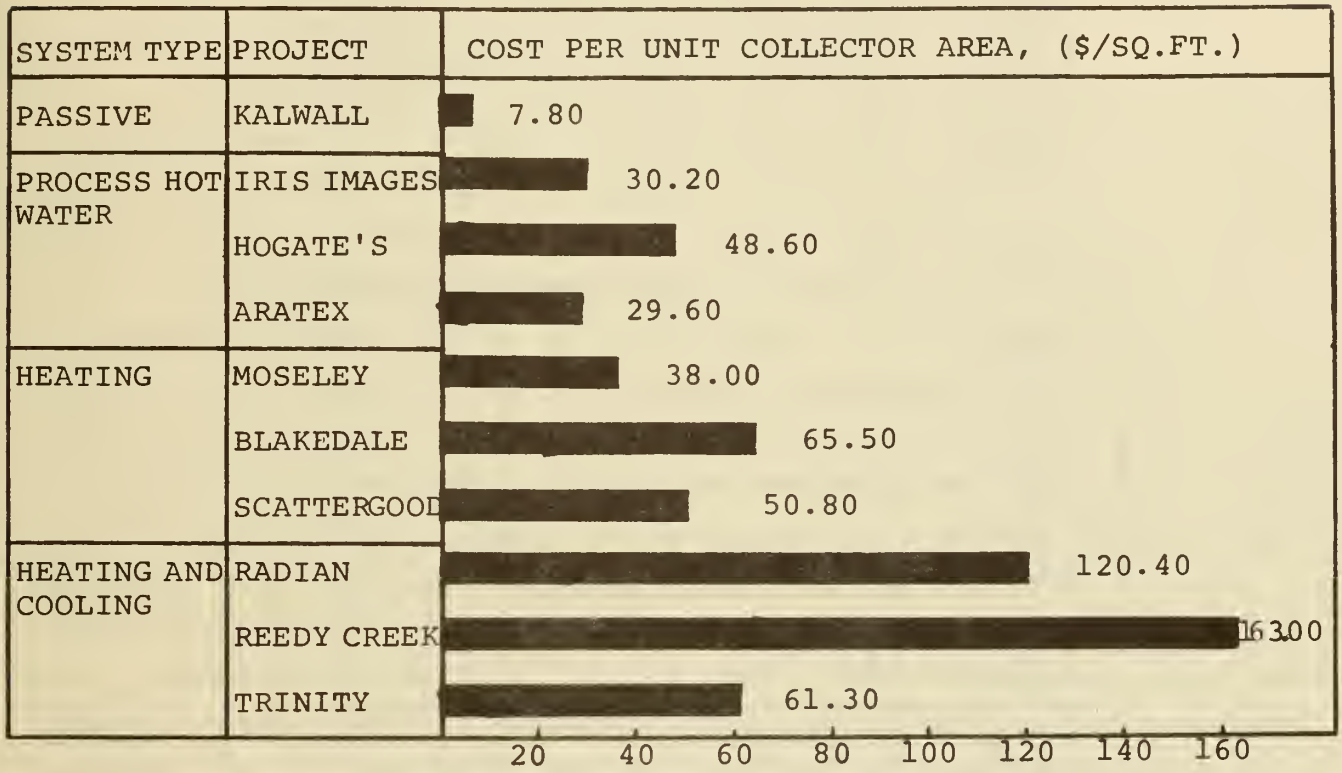


FIGURE V-1 Total System Unit Cost

Figure V-1 presents the total system unit cost for the ten projects. The significant variation evident in these total cost figures will be investigated in this section through an analysis of the category costs.

A. COLLECTOR ARRAY CATEGORY

- Collector Array, Materials and Delivery Costs

Table V-1 shows materials costs and delivery costs for the ten systems. For most of the systems, the delivery cost could not be separated from the materials costs. The most meaningful cost representations for comparison are the normalized cost per collector area and percent of total system cost columns.

TABLE V-1. COLLECTOR ARRAY MATERIALS AND DELIVERY COSTS

PROJECT	MATERIALS BARE COST AS REPORTED	MATERIALS BARE COST (1977 $'s)	GENERAL (G) OR SUB (S)	MATERIALS COST W/OH&P (1977 $'s)	MATERIALS COST ($/sq.ft.)	MATERIALS COST PERCENT OF TOTAL COST	DELIVERY BARE COST AS REPORTED	DELIVERY BARE COST AS REPORTED	GENERAL (G) OR SUB (S)	DELIVERY COST W/OH&P (1977 $'s)	DELIVERY COST (1977 $'s)	DELIVERY COST PERCENT OF TOTAL	MATERIALS & DELIVERY W/OH&P (1977 $'s)	MATERIALS & DELIVERY COST ($/sq.ft.)	PERCENT OF TOTAL COST	COLLECTOR AREA (sq.ft.)
KALWALL	6,320	6,790	G	8,485	4.8	63	None	None	None	None	None	None	8,485	4.8	63	1,750
IRIS IMAGES	3,345	3,595	G	4,490	7.5	25	a	a	a	a	a	a	4,495	7.5	25	600
HOGATE'S	71,030	71,030	G	88,790	15.2	33	925	925	S	1,020	0.2	<1	89,810	15.4	33	5,840
ARATEX	57,260	57,260	G	71,575	11.3	39	620	620	G	775	0.1	<1	72,350	11.4	39	6,350
MOSELEY	2,485	2,670	G	3,335	8.9	23	a	a	a	a	a	a	3,335	8.9	23	376
BLAKEDALE	7,590	8,150	G	10,190	11.0	17	a	a	a	a	a	a	10,190	11.0	17	924
SCATTERGOOD	31,935	34,300	G	42,875	19.1	38	810	870	G	1,090	0.5	1	43,965	19.6	39	2,240
RADIAN	9,145	9,820	G	12,275	35.1	29	145	155	G	195	0.6	<1	12,470	35.7	29	350
REEDY CREEK	361,435	361,435	S	397,580	103.5	64	a	a	a	a	a	a	397,580	103.5	64	3,840
TRINITY	254,600	254,600	G	318,250	20.4	33	a	a	a	a	a	a	318,250	20.4	33	15,633

[a] Not available - delivery costs included in materials cost.

The Kalwall system has the lowest cost per collector area, $4.80/ft^2. The collector array for this passive system is simply a wall consisting of two layers of fiberglass reinforced plastic sheet bonded to an aluminum grid core (See Figure V-2). No delivery cost was incurred since the panels are manufactured at the site. The cost of removing the old panels from the wall is included in the collector mounting category.

The process hot water and space heating systems all use flat plate collectors. Materials costs for the flat plate collectors vary from $7.50/ft^2 to $19.10/ft^2 and average $12.15/ft^2. Percent of total system costs varies from 17% to 40% and averages 30%.

Iris Images and Moseley have site-built collectors, as opposed to factory-built collector panels. One would expect lower materials cost for site-built collectors, and, indeed, these two systems have the lowest materials cost of the flat plate collector systems. The Iris Images collector system has one cover of corrugated fiberglass reinforced plastic, factory-built absorber plates, and 1-1/2" isocyanurate back insulation, (R-9.5), only (See Figure V-3).

Moseley collectors, with a larger materials costs than Iris Images, have a single tempered glass cover, site-built absorber plates, 1-1/2" wood side insulation, R-1.25, and 4" fiberglass batt back insulation, R-17 (See Figure V-4).

The factory-built collector panel arrays' materials cost range from $19.10/ft^2 at Scattergood to $11.00/ft^2 at Blakedale and average $14.15/ft^2.

The Scattergood system uses Solaron air collectors, double glazed with tempered glass, flat black steel absorber plates, internal manifolds and 3-1/2" fiberglass back insulation, R-15.

The Hogate's system uses Sunworks collectors double glazed with water white tempered glass, selective surface copper absorber plates, internal manifolds, and 2-1/2" fiberglass insulation, R-10. The collectors used at Hogate's are the most efficient of the flat plate collectors employed in the systems studied.

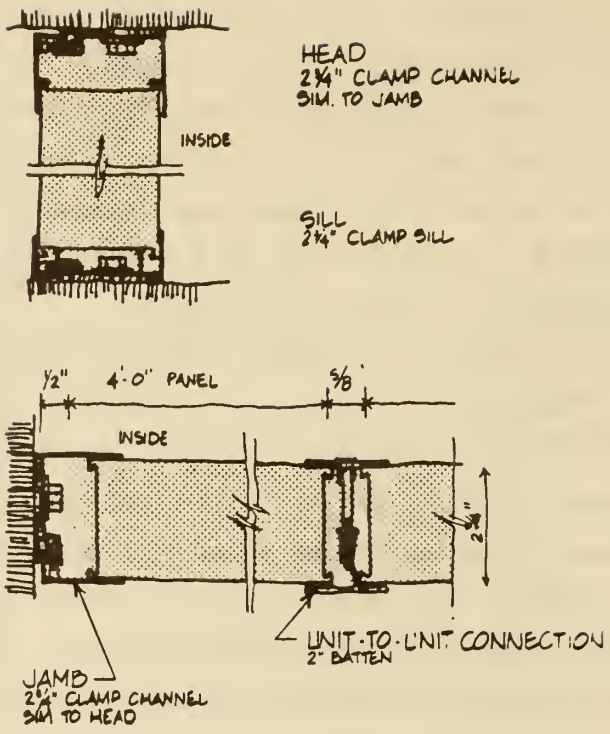


FIGURE V-2

Kalwall Passive Solar Wall

The Aratex system uses Ying collectors which are single glazed with UV stabilized polycarbonate, flat black aluminum absorber plates, externally manifolded, with 1" and 3" polyurethane side and back insulation, R-6 and R-19 respectively.

The Blakedale system uses PPG collectors. Originally, collectors with aluminum absorber plates were installed, which were subsequently replaced at no charge by the manufacturer with collectors with copper absorber plates. The costs reported are therefore for the original aluminum absorber plate collectors with double glazing of tempered glass, external manifolds, and 2-1/2" fiberglass insulation, R-10.5.

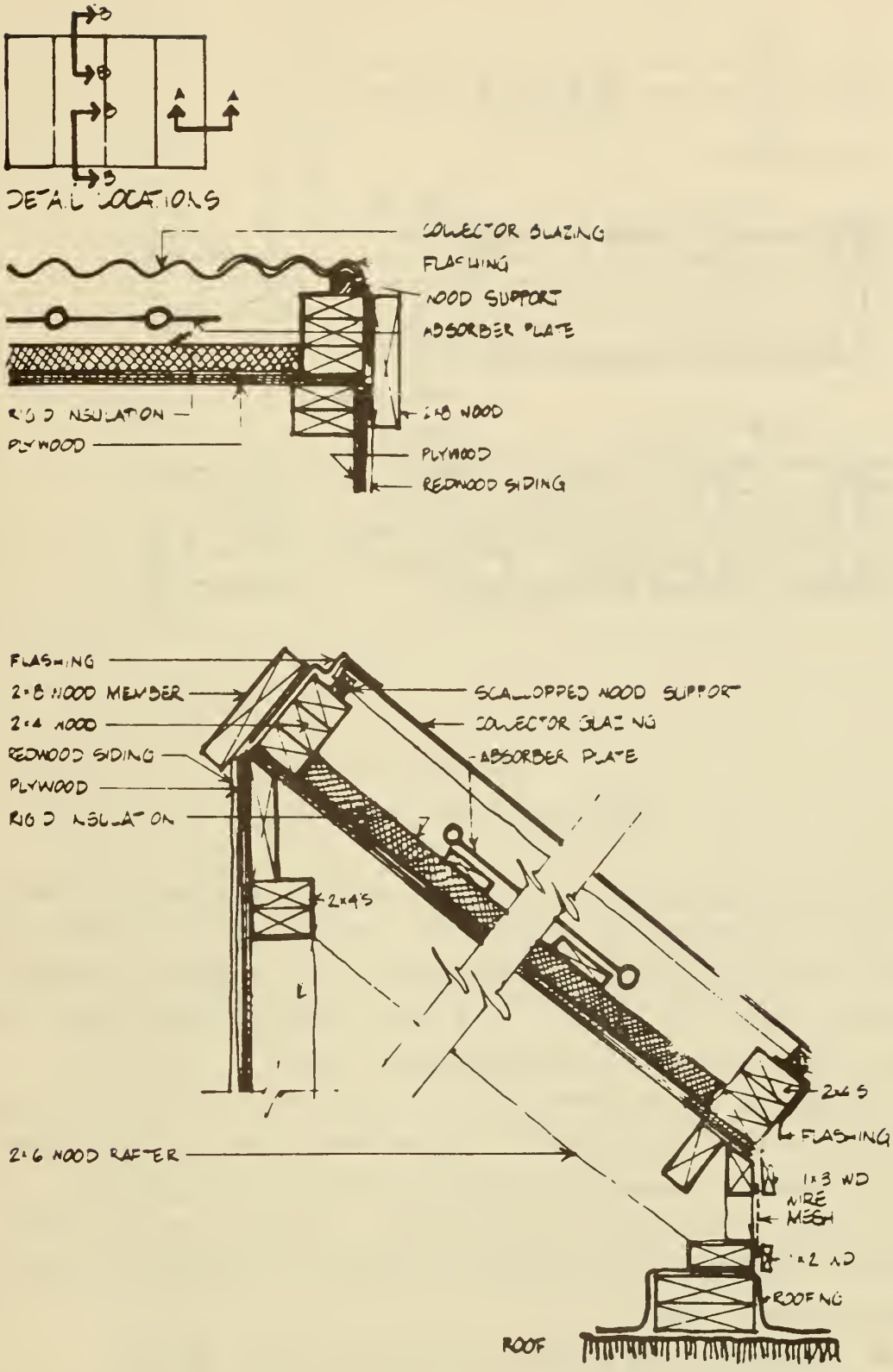


FIGURE V-3

Iris Images Collector Details

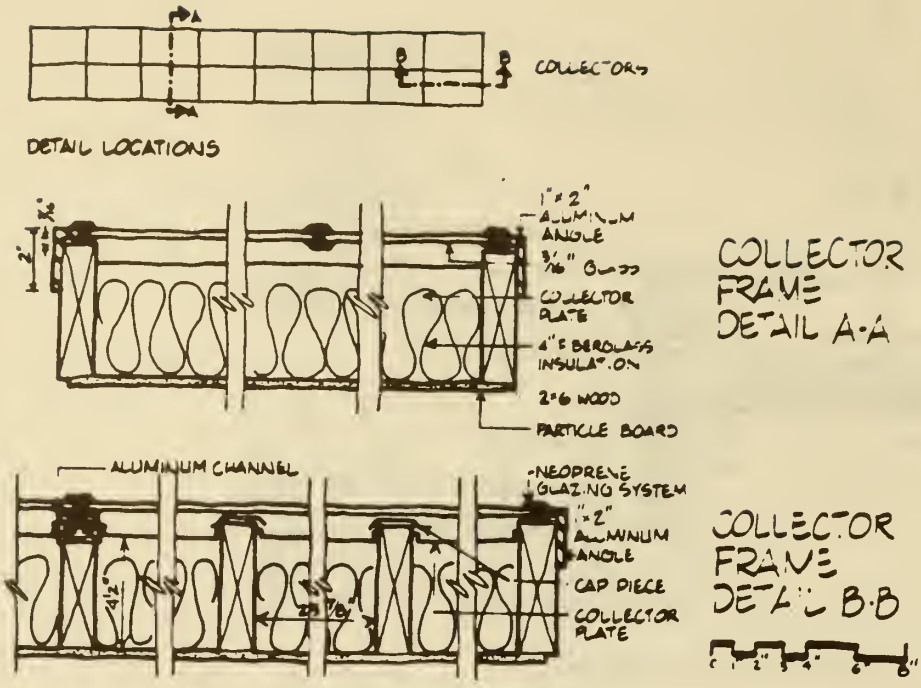


FIGURE V-4

Moseley Collector Detail

All of the space heating and cooling systems studied use tracking, concentrating collectors. The Radian and the Trinity systems both use Northrup collectors. The Radian collector materials cost, $35.10/ft^2, is significantly higher than the Trinity collector materials cost, $20.40/ft^2.

The Reedy Creek system has by far the largest unit collector materials cost, $103.50/ft^2. The system uses an innovative collector design, especially built for this application. Since the collectors form the building roof, credit for the cost of a similarly insulated replacement roof was given and is reflected in the category costs.

- Collector Array Mounting or Assembly Costs

Table V-2 shows costs of mounting or assembling collectors and costs of connecting collectors to a manifold. For most of the systems the manifold connection costs could not be obtained and are included in either the collector mounting or piping category

TABLE V-2. COLLECTOR ARRAY MOUNTING AND MANIFOLD CONNECTION COSTS

PROJECT	ASSEMBLY BARE COSTS AS REPORTED	MOUNTING BARE COSTS AS REPORTED	MOUNTING OR ASSEMOLY BARE COSTS (1977 $'s)	MAN HOURS	GENERAL (G) OR SUB (S)	MOUNTING OR ASSEMBLY COST W/OH&P (1977 $'s)	MOUNTING OR ASSEMBLY COST ($/SqFt)	PERCENT OF TOTAL COSTS	CON-NECTION BARE COSTS AS REPORTED	CONNECTION BASE COSTS (1977 $'s)	MAN HOURS	GENERAL (G) OR SUB (S)	CONNECTION COST W/OH&P (1977 $'s)	CONNECTION COST ($/SqFt)	PERCENT OF TOTAL COST	COLLECTOR AREA, (SqFt)
KALWALL	b	1,820	1,955	c	S	2,150	1.2	16	b	b	b	b	b	b	b	1,750
IRIS IMAGES	575	b	620	82	G	775	1.3	4	775	830	112	G	1040	1.7	6	600
HOGATES	b	15,100	15,100	c	S	16,610	2.8	6	a	a	a	a	a	a	a	5,840
ARATEX	b	1,740	1,740	56	G	2,175	0.3	1	185	185	a	G	230	<0.1	<1	6,350
MOSELEY	1,185	b	1,275	256	G	1,590	4.2	11	190	205	64	G	256	0.7	2	376
BLAKEDALE	b	430	460	64	S	510	0.5	<1	385	415	24	S	455	0.5	<1	924
SCATTERGOOD	b	8,155	8,760	500	G	10,950	4.9	8	a	a	a	a	a	a	a	2,240
RADIAN	b	465	500	76	G	625	1.8	1	a	a	a	a	a	a	a	350
REEDY CREEK	b	6,705	6,705	1,096	S	7,375	1.9	1	10,245	10,245	720	S	11,270	2.9	2	3,840
TRINITY	b	123,695	123,695	c	S	136,065	8.7	14	a	a	a	S	a	a	a	15,633

[a] Not available, included elsewhere.

[b] Does not apply

[c] Not available

costs. The manifold connection costs were usually small, $0.50 to $2.00/ft^2 and thus would have a small impact on the relationship among categories. The most meaningful cost representations for comparison are the normalized cost per collector area and percent of total system cost.

The flat plate collectors vary in mounting or assembly cost from $0.30/ft^2 to $4.90/ft^2, and average at $2.23/ft^2.

The assembly costs for the Moseley system ($4.20/ft^2) are higher than the assembly costs for the other site built system, Iris Images ($1.30/ft^2). This difference in assembly cost is accounted for by the fact that the Moseley absorber plates are site-built, while the Iris Images' contractor purchased factory-built absorber plates.

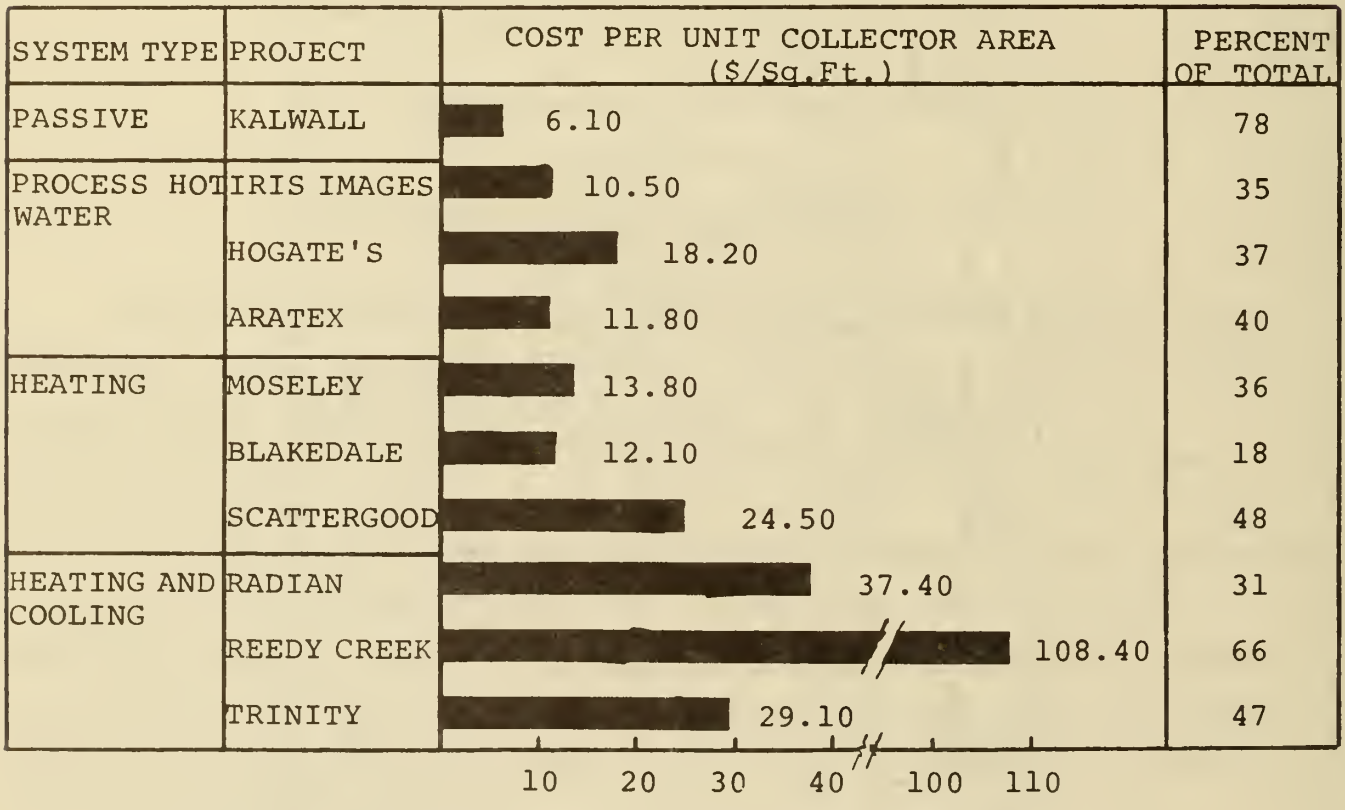


FIGURE V-5 Collector Array System Unit Costs

The mounting costs for the flat plate collectors are highest for the Scattergood system, in part because Scattergood is the

only planar collector array. All other arrays were the saw-tooth type. Further, the contractor reported experiencing substantial difficulty in mating adjacent collector modules to achieve proper alignment.

Of the flat plate collectors, the man-hours required for collector mounting or assembly are highest for the two site built collector systems, Iris Images and Moseley, and for the planar array, Scattergood.

Most of the contractors used cranes or cherry pickers to place the collectors on the roof and reported that this method worked well.

The manifold connection costs that are available indicate a range in cost from about $\$0.50/ft^2$ to $\$2.00/ft^2$. Flexible hose was used to connect the collectors to manifolds for the Aratex, Blakedale, Radian, and Reedy Creek systems. The other sites used rigid connections except Trinity which employed the special Northrup swivel coupling. Not enough data are available to assess the cost difference between connecting methods.

- Collector Array Costs Summary

A summary of the normalized costs per collector area for the collector array category are provided in Table V-3 and Figure V-5. For the flat plate collectors, collector array costs vary from $\$10.50/ft^2$ to $\$24.50/ft^2$, at an average of $\$15.10/ft^2$. Note that the site built collectors, with low materials cost and high assembly cost, lead to costs that are comparable to systems with factory built collector panels. Percent of total cost for the flat plate collectors vary from 19% to 47%, at an average of 36%.

B. SUPPORT STRUCTURE CATEGORY

Table V-4 shows collector support structure costs for the ten systems. Support structure costs vary from $\$2.80/ft^2$ to $\$15.70/ft^2$, at an average of $\$8.30/ft^2$. The support structure was on the average 15% of total system cost. The large variance in unit cost is attributable to the variety of materials and design schemes used in the systems' support structures. The support structures are described below.

The Iris Images collectors were mounted on wooden shed-like structures constructed on a flat roof (See Figure V-6).

TABLE V-3. COLLECTOR ARRAY COSTS SUMMARY

PROJECT	MATERIALS COST W/ OH&P (1977 $'s/SqFt)	DELIVERY COST W/ OH&P (1977 $'s/SqFt)	MOUNTING COST W/ OH&P (1977 $'s/SqFt)	MANIFOLD CONNECTOR W/ OH&P (1977 $'s/SqFt)	COLLECTOR ARRAY TOTAL COST (1977 $'s/SqFt)	COLLECTOR ARRAY PERCENT OF TOTAL COST	COLLECTOR AREA (SqFt)
KALWALL	4.8	NONE	1.2	b	6.1	79	1,750
IRIS IMAGES	7.5	a	1.3	1.7	10.5	35	600
HOGATES	15.2	0.2	2.8	c	18.2	39	5,840
ARATEX	11.3	0.1	0.3	<0.1	11.7	40	6,350
MOSELEY	8.9	a	4.2	0.7	13.8	36	376
BLAKEDALE	11.0	a	0.5	0.5	12.1	19	924
SCATTERGOOD	19.1	0.5	4.9	c	24.5	47	2,240
RADIAN	35.1	0.6	1.8	c	37.4	31	350
REEDY CREEK	103.5	a	1.9	2.9	108.4	67	3,840
TRINITY	20.4	a	8.7	c	29.1	47	15,633

a. Not available,
b. Does Not Apply.
c. Not Available, Included Elsewhere

TABLE V-4. SUPPORT STRUCTURE COSTS

PROJECT	BARE COSTS AS REPORTED			BARE COSTS TOTAL (1977 $'s)	GENERAL (G) OR SUB (S)	W/OH&P 1977 TOTAL	COLLECTOR AREA (SqFt)	$/SQ. FT.	PERCENT OF TOTAL COSTS	DESCRIPTION
	MATERIALS	LABOR	TOTAL							
KALWALL	None	None	None	None	None	None	None	None	None	
IRIS IMAGES	1,610	1,610	3,220	3,460	G	4,325	600	7.2	24	Wood
HOGATES	a	a	46,415	46,415	S	51,055	5,840	8.7	19	Steel Beam
ARATEX	7,385	6,775	14,160	14,160	G	17,700	6,350	2.8	10	Angle iron triangle
MOSELEY	500	415	915	985	G	1,230	376	3.3	9	Galvanized Pipe
BLAKEDALE	7,485	3,750	11,325	12,165	G(S(4750))	14,320	924	15.6	24	Redwood/Cedar
SCATTERGOOD	14,045	5,220	19,265	20,690	G	25,860	2,240	11.5	22	Steel Building
RADIAN	2,600	1,500	4,100	4,405	G	5,505	350	15.7	13	Aluminum Angle
REEDY CREEK	a	a	16,310	16,310	S	17,940	3,840	4.7	3	Steel Curves for Ends of Troughs
TRINITY	45,483	23,200	68,685	68,685	G	85,855	15,633	5.5	9	Galvanized Steel

a) Materials/labor breakdown could not be obtained.

Aratex's support structure is steel angle triangles lag bolted to Douglas fir sleepers on wood blocks on a flat roof (See Figure V-7).

At Hogate's, welded steel I-beam support frames are attached to a flat roof for one bank of collectors (See Figure V-8 and to a mansard roof for the other bank (See Figure V-9). Each bank is two collectors high.

At Moseley, galvanized steel pipe was used to mount collectors on a flat roof. (Some of the steel pipe used was on hand prior to construction, and the cost of this pipe is not reflected in the cost figures.) Figure V-10 shows the Moseley collector support system.

The Blakedale collector support system is mounted on a sloping roof using wooden support frames. The support category also includes costs for aluminized Mylar reflectors facing two of the collector banks (See Figure V-11). The system is aesthetically compatible with the rest of the building.

The Scattergood system represents the only planar array among the ten systems. The support structure is plywood sheathing on purlins over steel rafters that angle against the building wall (See Figure V-12). The space under the structure houses mechanical equipment and the rock bin storage.

The basic collector frame for the Radian system was provided by the collector manufacturer, and the installer provided extra bracing. Aluminum angle legs are set in concrete filled pipes bolted to wood resting on a flat roof. Guy wires anchored to the roof hold the frames in place (See Figure V-13).

Since the collectors at the Reedy Creek system form the roof, the only support structure costs incurred are for steel pieces at the end of the collector troughs (See Figure V-14).

At the Trinity system, galvanized steel sheets were bent to form the channels that form the support structure frame (See Figure V-15). The frames are mounted on a flat roof.

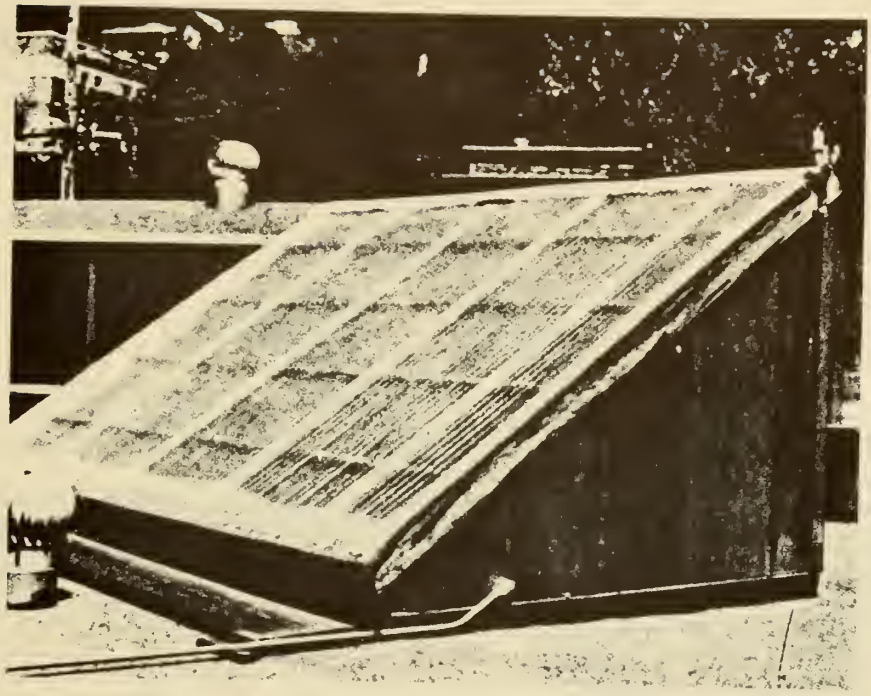


FIGURE V-6

Iris Images Support Structure

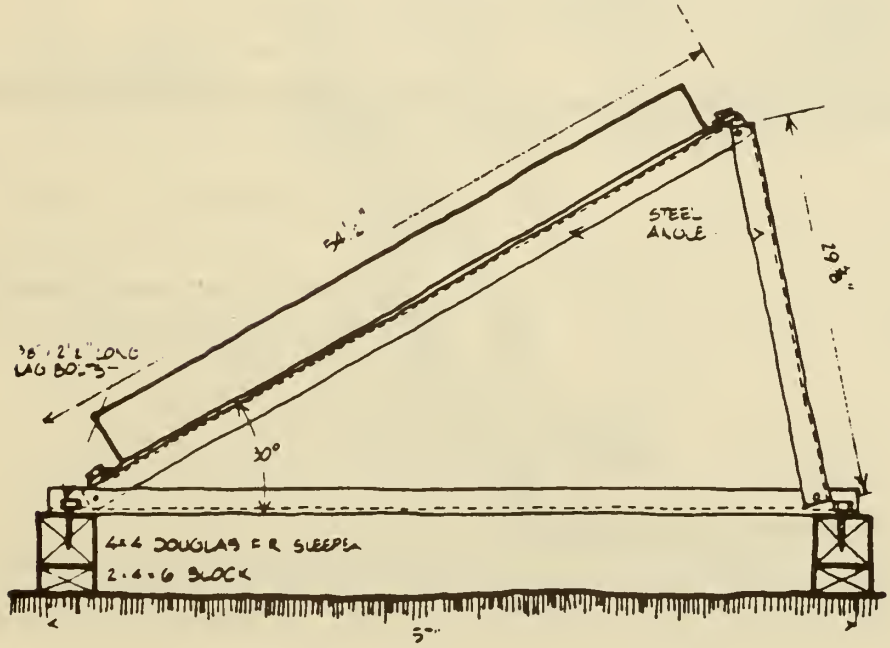


FIGURE V-7

Aratex Support Structure

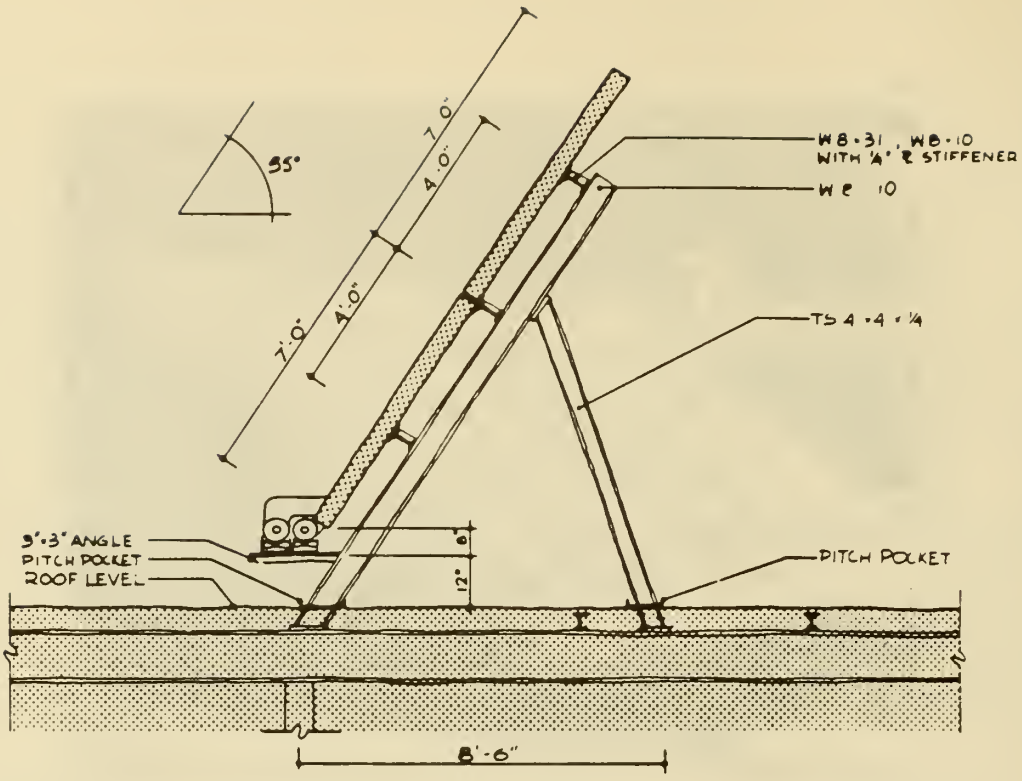


FIGURE V-8

Hogate's Support Structure, Flat Roof Section

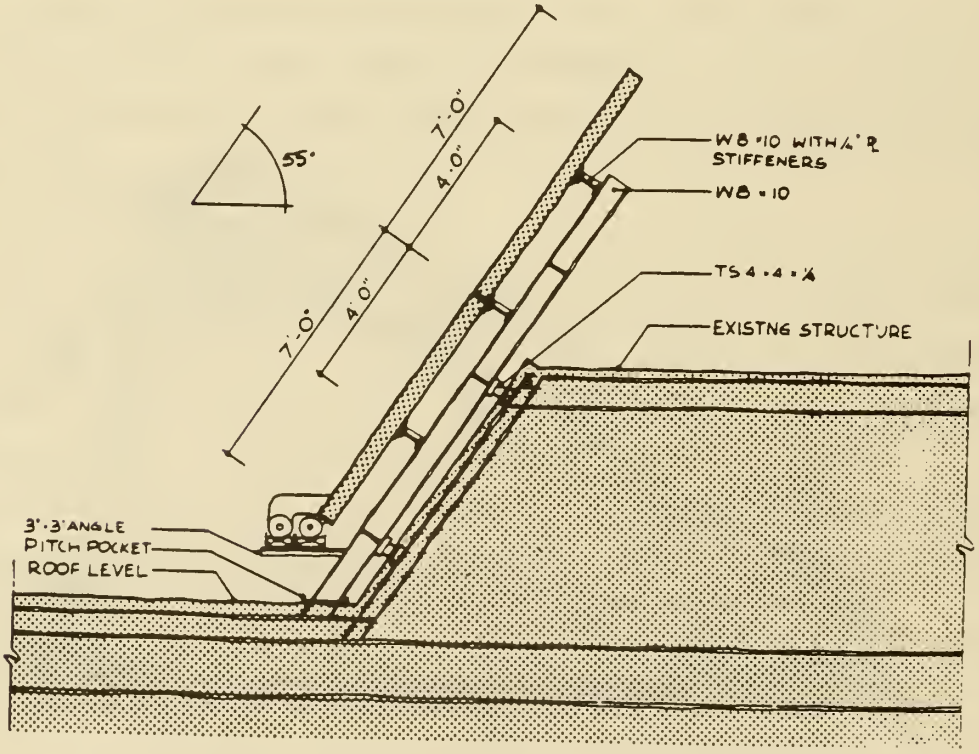
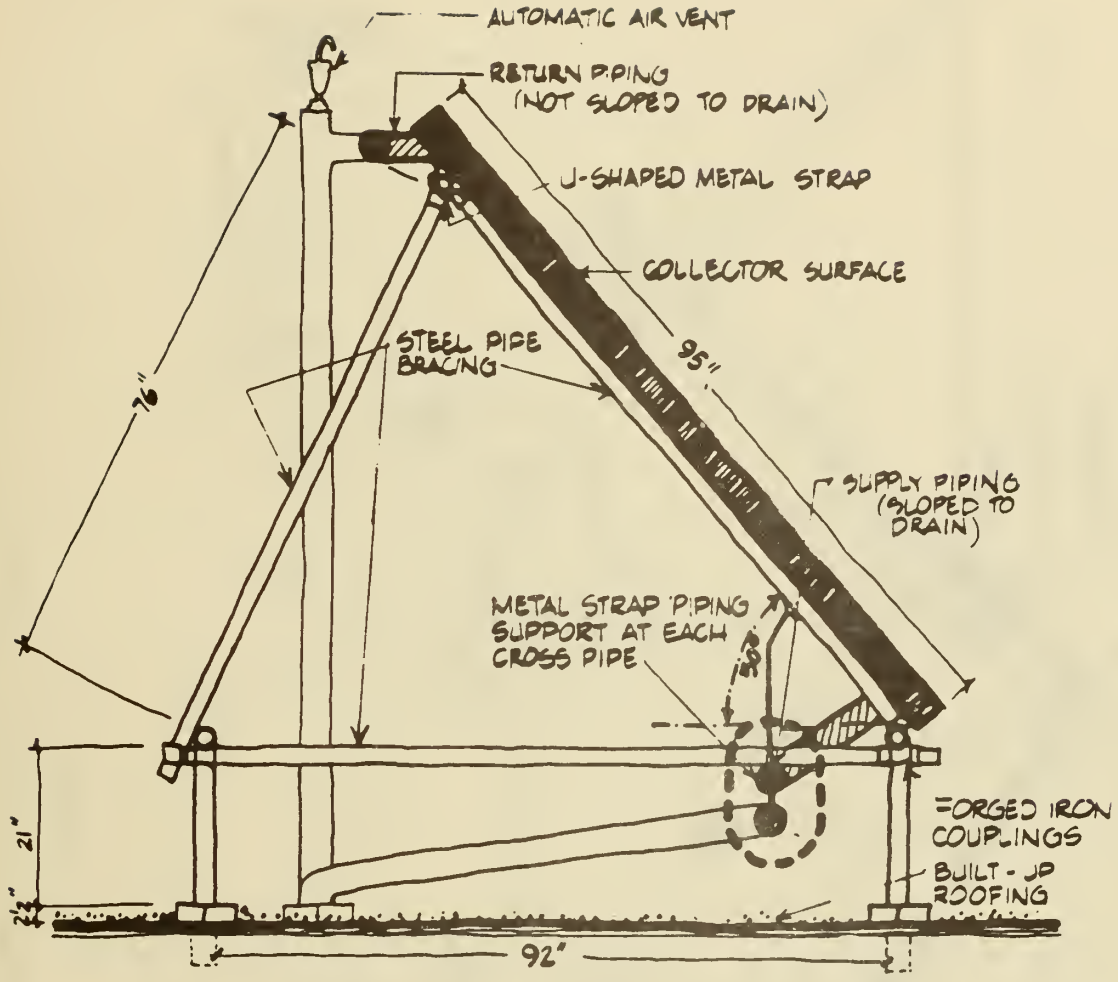


FIGURE V-9

Hogate's Support Structure, Raised Roof Section



COLLECTOR SUPPORT SECTION

FIGURE V-10

Moseley Support Structure

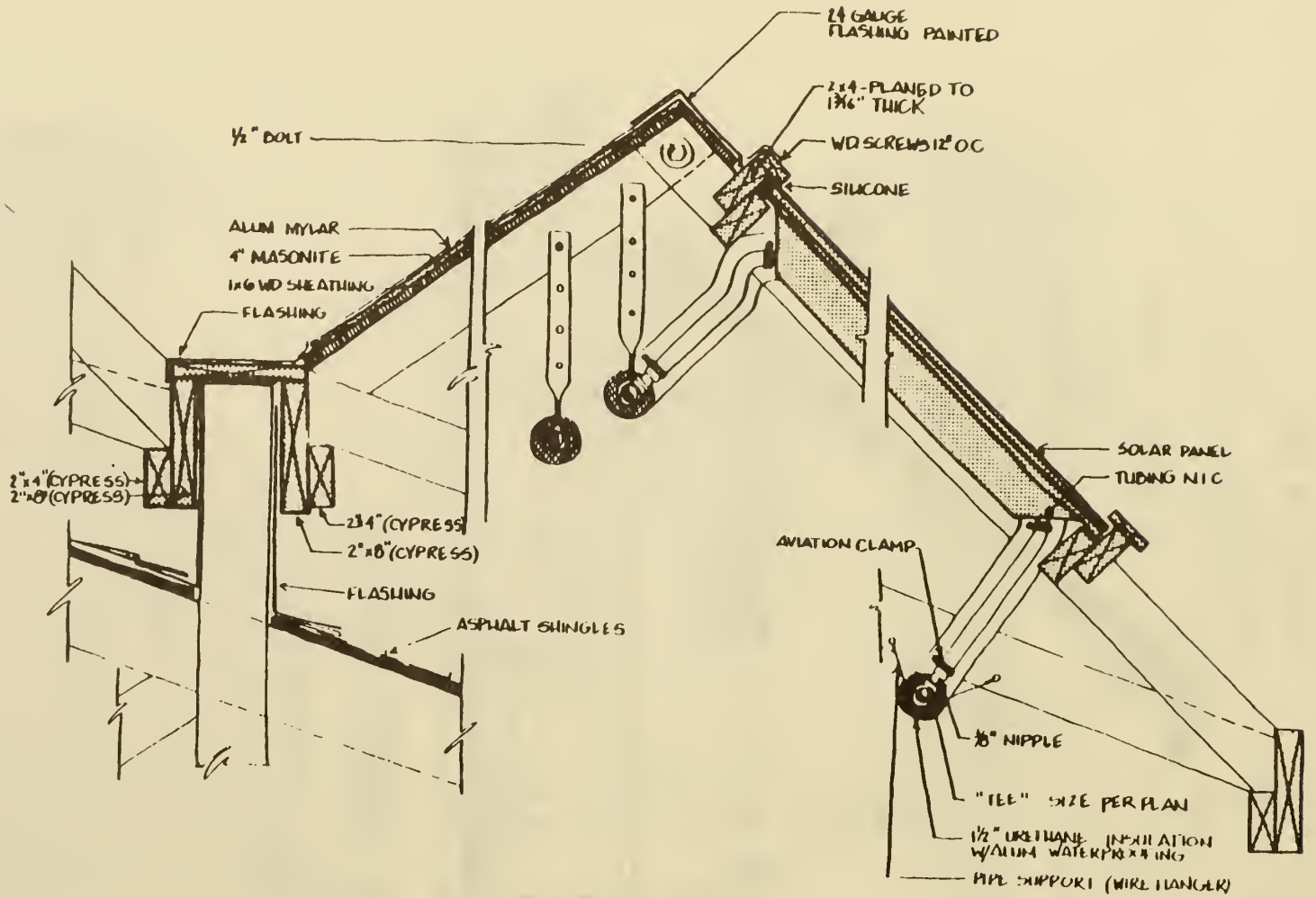


FIGURE V-11

Blakedale Support Structure

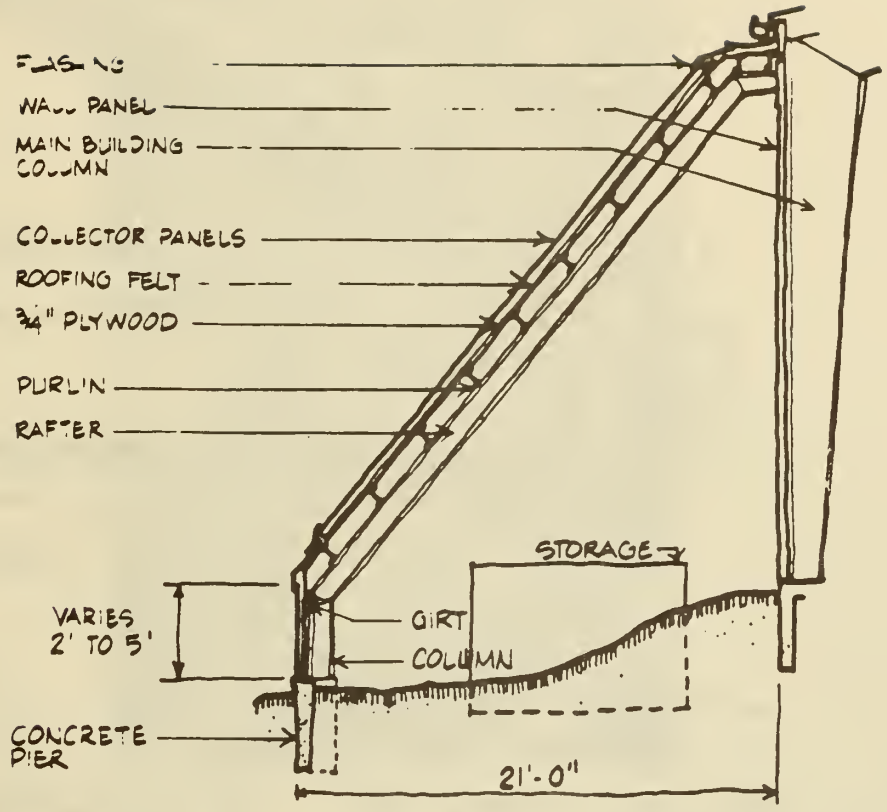


FIGURE V-12

Scattergood Support Structure

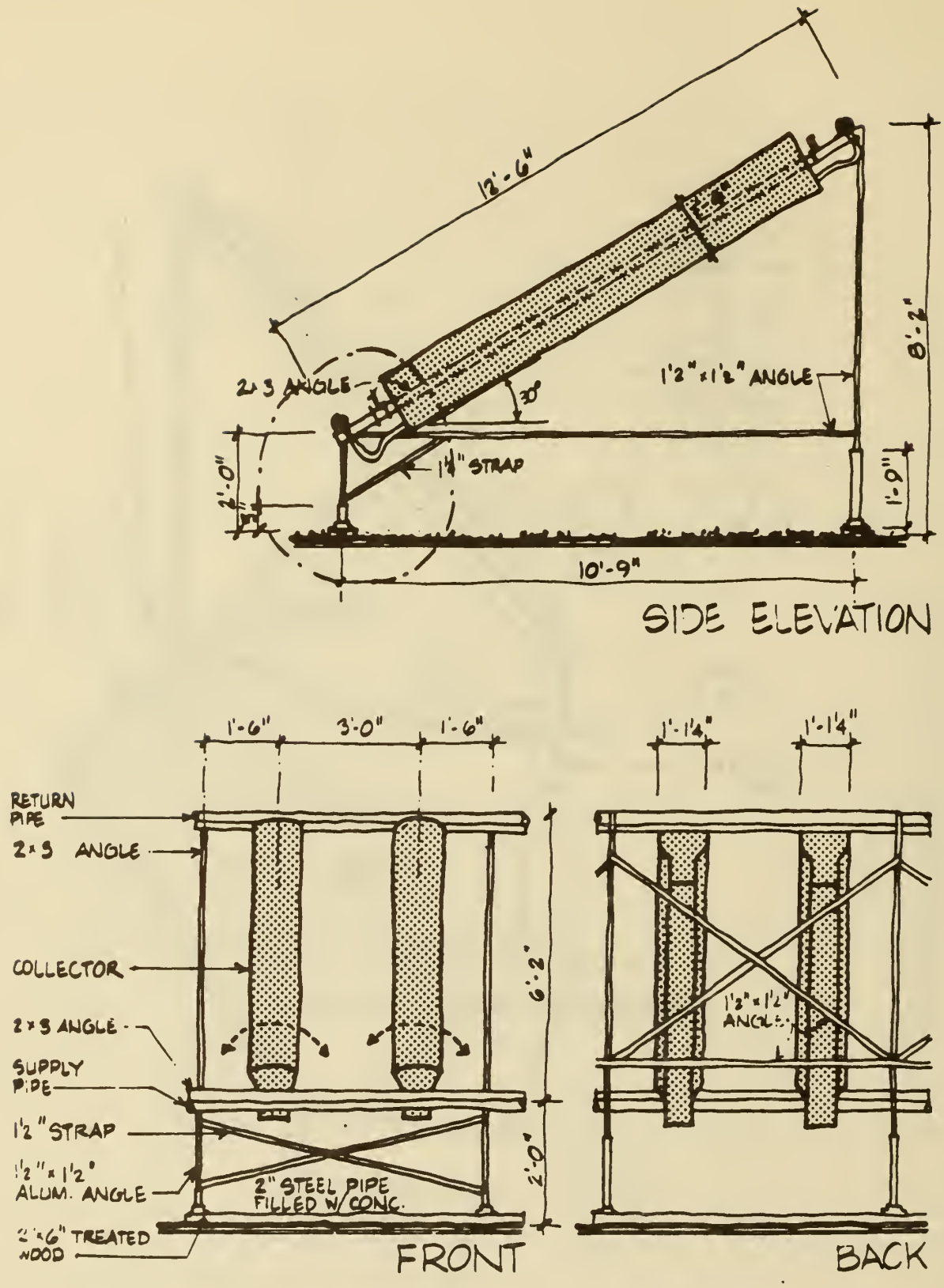


FIGURE V-13

Radian Support Structures

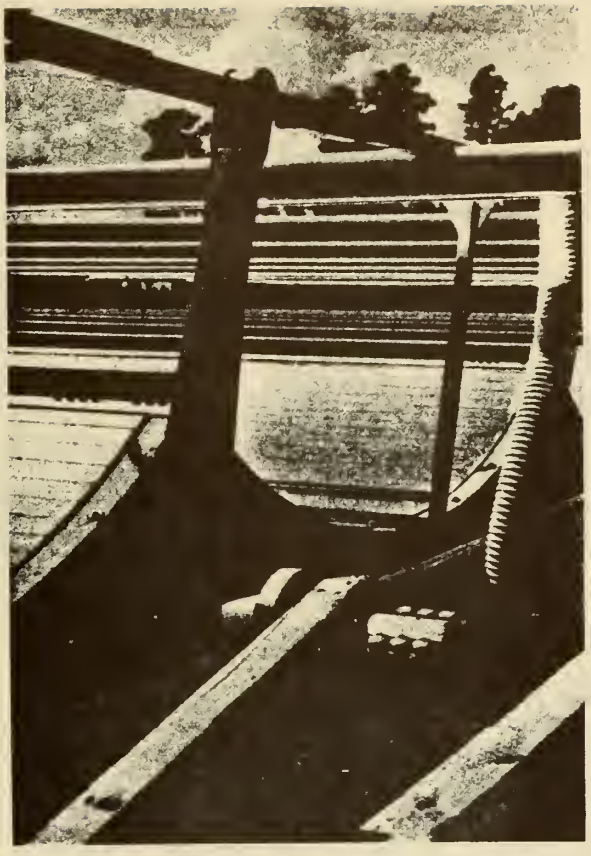
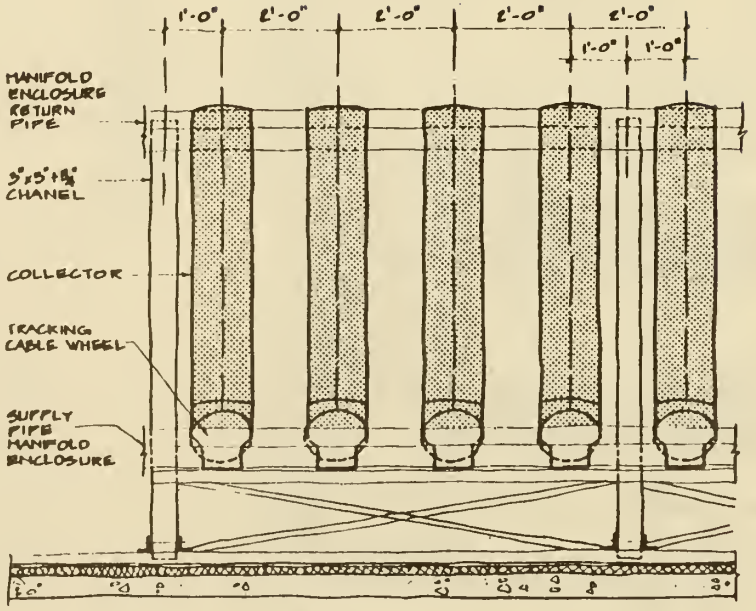
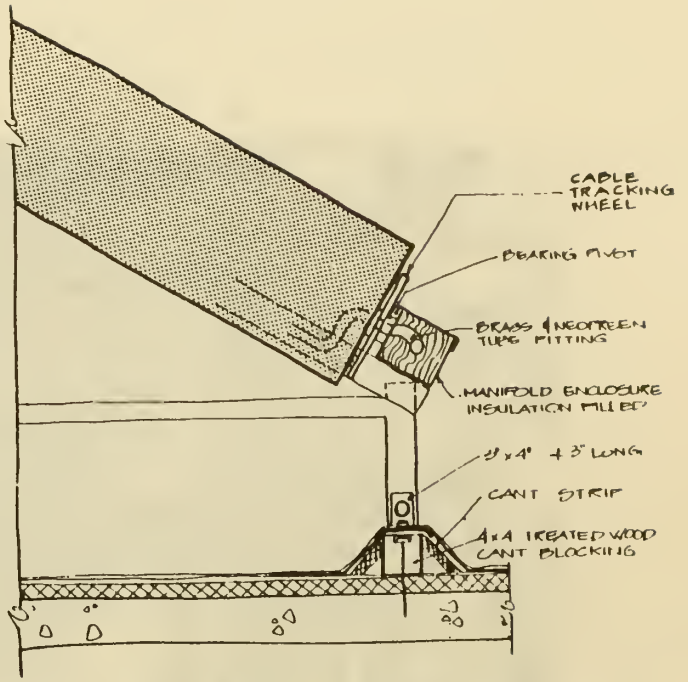


FIGURE V-14

Reedy Creek Support Structure



FRONT ELEVATION



COLLECTOR SECTION & ROOF DETAIL

FIGURE V-15 Trinity Support Structure

The more expensive structures seem to have higher ratios of materials to total cost. The less expensive structures are simpler in design, with less attention to aesthetic requirements. Figure V-16 graphically summarizes support structure unit costs.

C. PIPING, DUCTWORK, AND INSULATION CATEGORY

- Piping Costs

Table V-5 shows the piping category costs for the ten systems. The most meaningful cost representations are normalized cost per collector area and percent of total system cost.

The process hot water systems' piping costs range from $\$3.50/ft^2$ to $10.90/ft^2$, at an average of $\$7.90/ft^2$ or 22% of total cost. The Iris Images piping costs are much lower than the other two hot water systems, in part because the Iris Images system uses only one pump, as opposed to 4 and 5 for the other systems.

Of the space heating systems, the two liquid collection systems average $\$9.15/ft^2$ or 16% of total cost. The Blakedale system piping cost is high, in part because of long underground piping runs to the buried storage tanks. The piping runs for the air system, Scattergood, are naturally low, since piping is used only for the domestic hot water subsystem.

The space heating and cooling systems piping costs vary from $\$6.70/ft^2$ to $\$22.20/ft^2$, at an average of $\$14.70/ft^2$, 13% of total cost. Note that piping costs per collector area decrease as collector array area increases for the cooling system.

- Ductwork Costs

Table V-6 shows ductwork costs for the two systems for which any ductwork costs were attributable to the solar energy system. Comparison of costs is meaningless since ductwork costs for Scattergood represent collector to storage and storage to load energy transport systems, while ductwork costs for Radian are merely the costs for the distribution system for the solar heated and cooled air. The distribution system ductwork is included for these two sites because the solar energy systems employed completely separate distribution systems from the backup systems.

TABLE V-5. PIPING COSTS

PROJECT	BARE COSTS AS REPORTED			BARE COSTS (1977 $'s)	GENERAL (G) OR SUB (S)	W/OH&P (1977 $'s)	COLLECTOR AREA (SqFt)	$/SqFt	PERCENT OF TOTAL COST
	MATERIALS	LABOR	TOTAL						
KALWALL	None	None	None	None	None	None	1,750	None	None
IRIS IMAGES	565	1,155	1,720	1,850	G	2,310	600	3.9	13
HOGATES	23,140	27,875	51,015	51,015	G[S(2500)]	63,395	5,840	10.9	22
ARATEX	16,455	28,105	44,560	44,560	G	55,700	6,350	8.8	30
MOSELEY	750	420	1,170	1,255	G	1,570	376	4.2	11
BLAKEDALE	a	a	10,550	11,330	S[G(3790)]	13,075	924	14.1	22
SCATTERGOOD	740	295	1,035	1,110	G	1,390	2,240	0.6	1
RADIAN	a	a	6,400	6,875	S[G(1320)]	7,775	350	22.2	18
REEDY CREEK	28,185	25,150	53,335	53,335	S	58,670	3,840	15.3	9
TRINITY	60,775	34,250	95,025	95,025	S	104,530	15,633	6.7	11

a) Materials/labor breakdown could not be obtained.

TABLE V-6. DUCTWORK COSTS

PROJECT	BARE COSTS AS REPORTED			BARE COSTS (1977 $'s)	GENERAL (G) OR SUB-CONTRACTOR (S)	W/OH&P (1977 $'s)	COLLECTOR AREA (SqFt)	$/SqFt	PERCENT OF TOTAL COSTS
	MATERIAL	LABOR	TOTAL						
SCATTERGOOD	4,970	5,205	10,175	10,885	S[G(235)]	12,060	2,240	5.4	11
RADIAN	b	b	610	655	S	720	350	2.1	2

a) Only the Scattergood and Radian systems had ductwork costs attributable to solar system

b) Materials/labor breakdown could not be obtained.

- Insulation Costs

Table V-7 shows insulation costs for the systems. For the process hot water systems, insulation costs average at $1.40/ft^2 or 4% of total system cost. Iris Images, with the least expensive insulation (0.40/ft^2), has only 150 ft. of insulated pipe, 1" fiberglass (R-4), not exposed and therefore without covering. Hogates, at $2.30/ft^2, has 2" fiberglass (R-8), with aluminum covers on the roof and canvas wrapping inside the building. Aratex insulation cost $1.60/ft^2 and is 1" fiberglass (R-4) with aluminum covers outside and canvas wrapping inside.

The two space heating systems for which insulation cost information is available have an average insulation cost of $4.40/ft^2 or 8% of total system cost. The Moseley system, at $2.20/ft^2, has pipes insulated with 3/4" foam rubber covered by corrugated aluminum on the roof and with aluminum foil wrapped 1" fiberglass (R-4) inside. Blakedale, considerably more expensive at $7.00/ft^2, has 1" to 1-1/2" polyurethane (R-7 to R-9) covered with an aluminum jacket on the roof and with canvas wrappings inside the building. The long underground piping runs are insulated with 1" foam glass (R-6) covered with bitumastic.

The space heating and cooling systems have an average insulation cost of $5.60/ft^2 or 6% of total system cost. Radian, at $6.70/ft^2, has 1/2" foam rubber with no cover and 1" fiberglass (R-4) with a canvas wrapping inside the building. Reedy Creek, at $3.60/ft^2, has 3/4" foam rubber with a plastic and wire spiral wrapping outside the building and 1-1/2" fiberglass (R-6) with a paper and vapor barrier wrapping. Trinity insulation cost $6.50/ft^2 and consists of 1" fiberglass (R-4) with an aluminum cover outside the building, a mastic cover inside the building, and a bitumastic cover on the long underground pipe runs to storage.

- Piping, Ductwork, and Insulation Cost Summary

Figure V-17 presents a graphical summary of piping ductwor and insulation unit costs. A summary of the normalized unit cost information for piping, ductwork and insulation categories is provided in Table V-8. The combined total cost of these categories

TABLE V-7. INSULATION COSTS

PROJECT	BARE COSTS AS REPORTED			BARE COSTS (1977 $'s)	GENERAL (G) OR SUB (S)	TOTAL COST W/OH&P (1977 $'S)	COLLECTOR AREA (SqFt)	$/SqFt	PERCENT OF TOTAL COST
	MATERIAL	LABOR	TOTAL						
KALWALL	None	None	None	None	None	None	1,750	None	None
IRIS IMAGES	125	55	180	195	G	245	600	0.40	1
HOGATES	a	a	12,000	12,000	S	13,200	5,840	2.3	5
ARATEX	a	a	9,400	9,400	S	10,340	6,350	1.6	6
MOSELEY	550	55	605	650	G	810	376	2.2	6
BLAKEDALE	2,290	3,130	5,420	5,820	S[G(205)]	6,435	924	7.0	10
SCATTERGOOD	a	a	a	a	S	a	2,240	a	a
RADIAN	1,210	525	1,735	1,865	G	2,330	350	6.7	6
REEDY CREEK	4,285	8,430	12,715	12,715	S	13,985	3,840	3.6	2
TRINITY	a	a	92,015	92,015	S	101,215	15,633	6.5	11

[a]Not Available - included elsewhere.

TABLE V-8. PIPING, DUCTWORK, AND INSULATION COSTS SUMMARY

PROJECT	PIPING $ 1977 W/ OH&P ($/SqFt)	DUCTWORK $ 1977 W/ OH&P ($/SqFt)	INSULATION $ 1977 W/ OH&P ($/SqFt)	TOTAL ($/SqFt) W/ OH&P	PERCENT TOTAL	COLLECTOR AREA (SqFt)
KALWALL	NONE	NONE	NONE	NONE	NONE	1,750
IRIS IMAGES	3.9	a	0.4	4.0	14	640
HOGATES	10.9	a	2.3	13.2	27	5,840
ARATEX	8.8	a	1.6	10.4	36	6,350
MOSELEY	4.2	a	2.2	6.3	17	376
BLAKEDALE	14.1	a	7.0	21.1	32	924
SCATTERGOOD	0.6	5.4	b	6.0	12	2,240
RADIAN	22.2	2.1	6.7	30.9	26	350
REEDY CREEK	15.3	a	3.6	18.9	11	3,840
TRINITY	6.7	a	6.5	13.2	21	15,633

a) Does not apply.

b) Not available - included in ductwork.

is also shown for each system. For the process hot water systems, this combined cost varies from $4.00/ft^2 to 13.20/ft^2, at an average of $9.20/ft^2 or 25% of total system cost. For the space heating systems, the costs vary from $6.00/ft^2 to $21.10/ft^2, at an average of $11.10/ft^2 or 20% of total system cost. For the space heating and cooling systems, costs vary from $13.20/ft^2 to $30.90/ft^2, with an average value of $21.00/ft^2 or 19% of total system cost.

E. STORAGE

Tables V-9 and V-10 show cost information on storage category costs for the ten systems. A variety of cost representations are shown. Costs per gallon of storage capacity is particularly meaningful since the ratio of collector area to storage size varies considerably. Figure V-18 through V-26 are taken from the referenced Solar Project Description Documents and illustrate the storage systems for all the projects except Kalwall. The Kalwall system simply used the existing concrete slab with added insulation around the perimeter for heat storage.

For the two-tank systems (Hogates, Reedy Creek and Trinity), normalized storage costs average at $6.40/ft^2 collector area, $2.10/gallon storage capacity, and 7% of total system cost.

If we assume that Scattergood's 65 ton rockbed storage has a thermal capacity equivalent to 300 gallons of water, then the remaining active systems' normalized storage costs average at $4.60/ft^2 collector area, $1.92/gallon storage capacity and 8% of total system cost.

For the pressurized tank systems (Iris Images, Hogates, Reedy Creek and Trinity) the storage materials and delivery costs average $3.30/ft^2 collector area and $1.60/gallon storage capacity. For the non-pressurized systems (Aratex, Moseley, Blakedale, and Radian) the storage materials and delivery average $3.90/ft^2 collector area and $0.90/gallon storage capacity.

For the steel tank systems (Hogates, Moseley, Blakedale, Reedy Creek, and Trinity) the storage materials and delivery costs average $4.00/ft^2 collector area and $1.00/gallon storage capacity.

TABLE V-9 STORAGE COSTS

PROJECT	BARE COSTS AS REPORTED					BARE COST (1977 $'s)	GENERAL (G) OR SUB (S)	W/OH&P (1977$'s)	COLLECTOR AREA (SqFt)	$/SqFt	PERCENT OF TOTAL COST	$/GAL
	MATERIALS	DELIVERY	INSTALLATION	INSULATION	TOTAL							
KALWALL	a	b	a	1,025	1,025	1,101	G[S(50)]	1,370	1,740	0.8	10	---
IRIS IMAGES	800	b	140	---	940	1,010	G	1,260	600	2.1	7	3.50
HOGATES	10,465	b	3,100	8,000	20,565	20,565	G[S(10,100)]	24,195	5,840	4.1	9	2.42
ARATEX	8,000	b	875	2,500	12,375	12,375	G[S(3,500)]	14,945	6,350	2.4	8	1.19
MOSELEY	850	b	20	320	1,190	1,280	G [S(320)]	1,545	376	4.1	11	0.77
BLAKEDALE	3,765	b	200	1,950	6,355	5,915	G[S(2,150)]	7,595	924	8.2	13	1.52
SCATTERGOOD	2,310	b	3,960	b	6,270	6,735	G	8,420	2,240	3.8	7	113/ ton
RADIAN	1,415	50	45	430	1,940	2,085	G	2,605	350	7.4	6	1.74
REEDY CREEK	23,140	b	1,655	13,305	38,100	38,100	S	41,910	3,840	10.9	6	2.10
TRINITY	36,625	b	16,880	6,000	59,505	59,505	S	65,460	15,635	4.2	7	1.64

a) Does not apply

b) Cost breakdown could not be obtained. Cost included in materials costs.

TABLE V-10 STORAGE MATERIALS AND INSULATION COSTS

PROJECT	MATERIALS & DELIVERY W/OH&P 1977	CAPACITY (gallons)	MATERIALS COST ($/gallon)	INSULATION COSTS W/OH&P 1977	INSULATION COST ($/gallon)	SURFACE AREA OF TANK (SqFt)	$/SQ FT TANK	R-VALUE OF INSULA-TION	INSULATION ($/gal.-R)	INSULATION PERCENT OF TOTAL STORAGE COSTS
KALWALL	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE	NONE
IRIS IMAGES	945	360	2.63	a	a	a	a	a	a	a
HOGATES	13,085	10,000	1.31	8,800	0.88	1,015	8.69	26	0.034	36
ARATEX	10,000	12,500	0.80	3,850	0.31	755	5.11	17	0.018	26
MOSELEY	1,140	2,000	0.57	380	0.19	245	1.54	17	0.011	24
BLAKEDALE	5,055	5,000	1.01	2,305	0.46	440	5.24	26	0.018	30
SCATTERGOOD	2,730	65 tons b	41.98/ton	a	a	a	a	a	a	a
RADIAN	1,965	1,500	1.31	575	0.38	195	2.96	19	.022	22
REEDY CREEK	25,455	20,000	1.27	14,635	0.73	1,470	9.96	17	.038	35
TRINITY	40,290	40,000	1.01	6,000	0.17	2,525	2.62	19	.009	10

a) Insulation costs could not be separated from materials costs.

b) Thermal capacity approximately equivalent to 3,000 gallons of water.

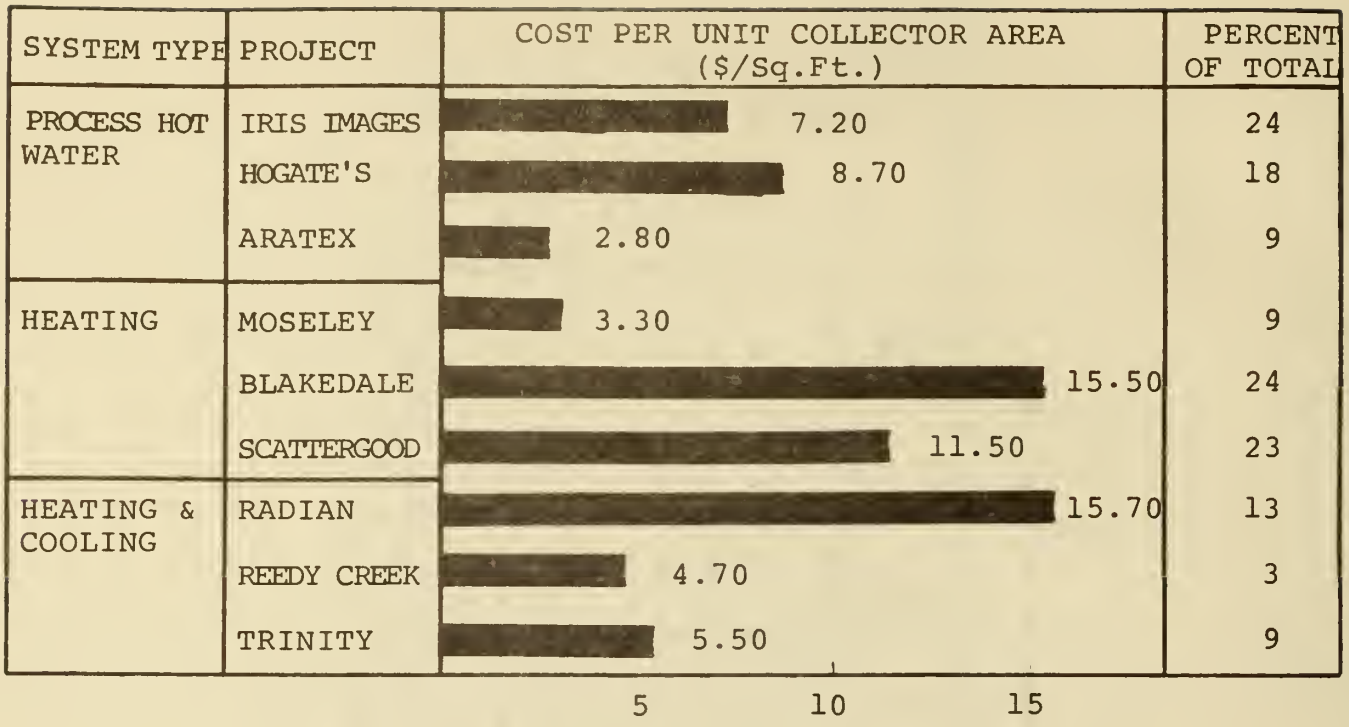


FIGURE V-16
COLLECTOR SUPPORT SYSTEM UNIT COSTS

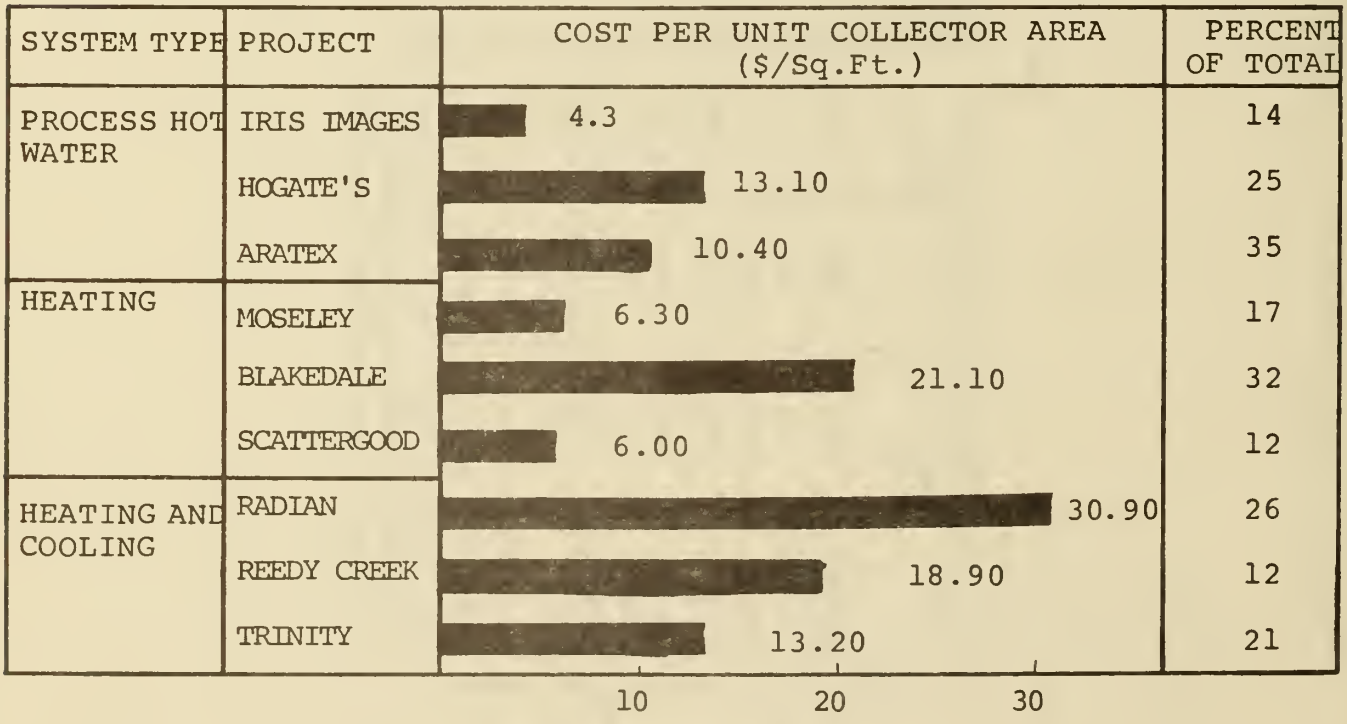


FIGURE V-17
PIPING, DUCTING, AND INSULATION SYSTEM UNIT COSTS

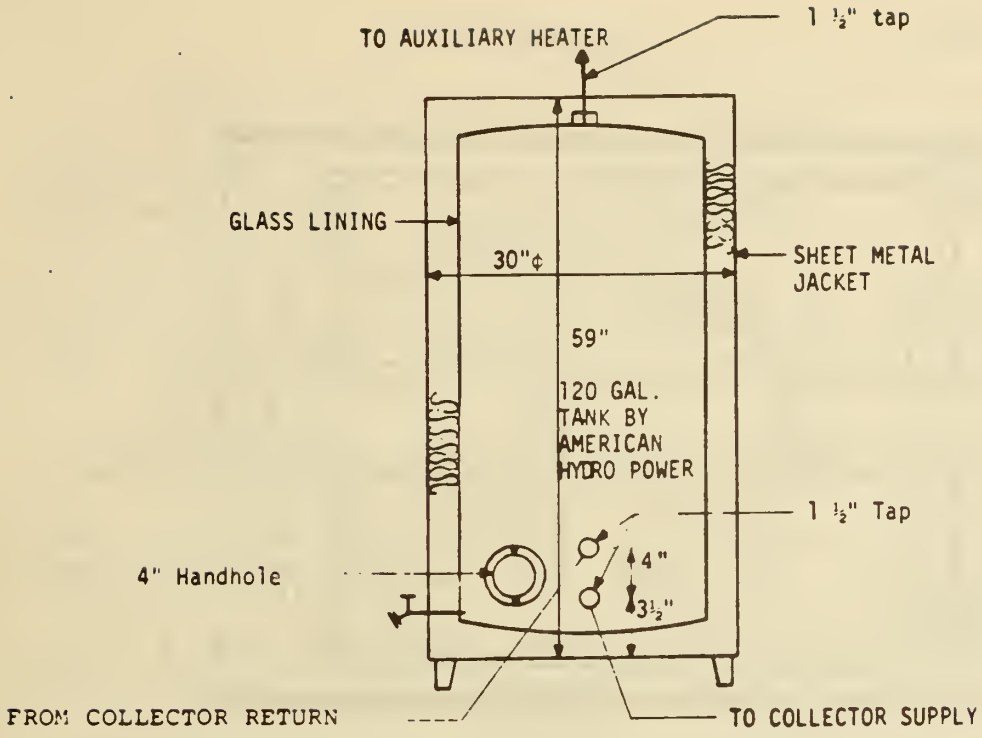


FIGURE V-18

Iris Images Storage Tank: Typical of Three

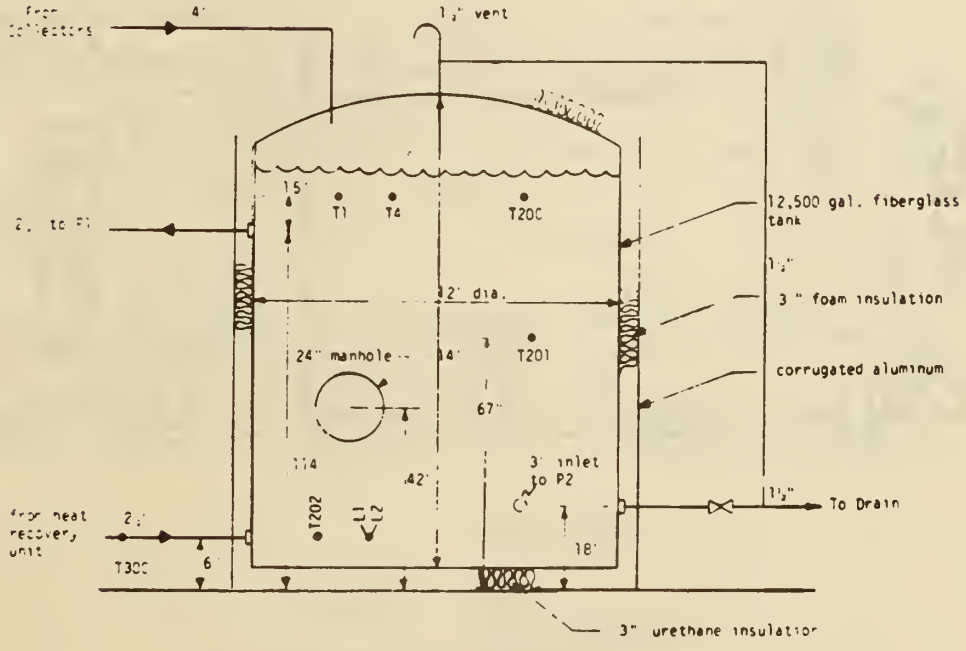
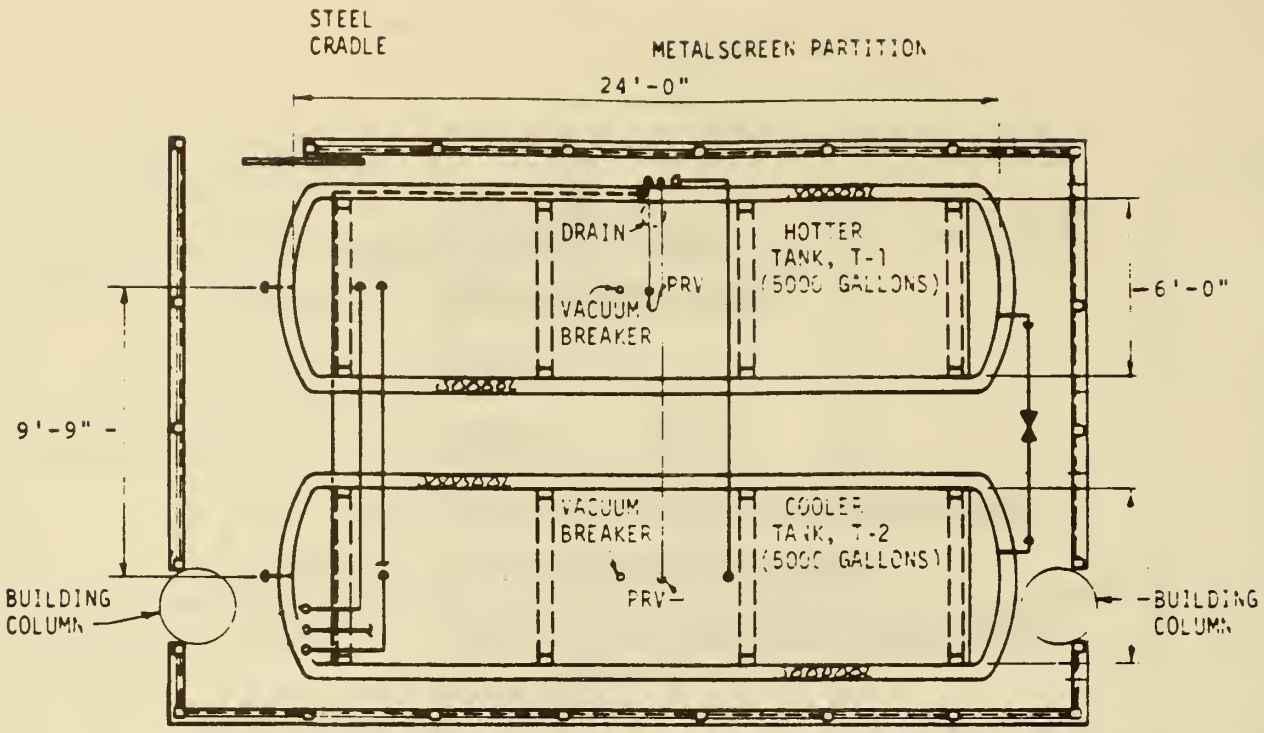
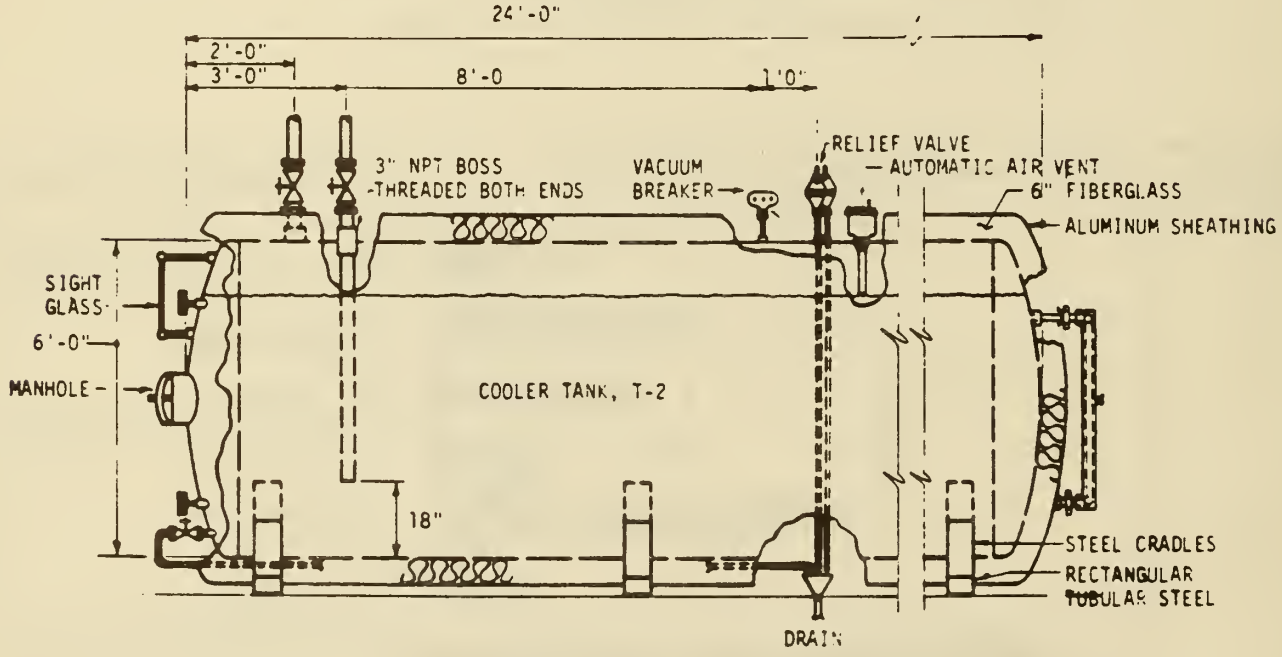


FIGURE V-19

Aratex Storage Tank



Top View



Side View

FIGURE V-20

Hogate's Storage Tanks

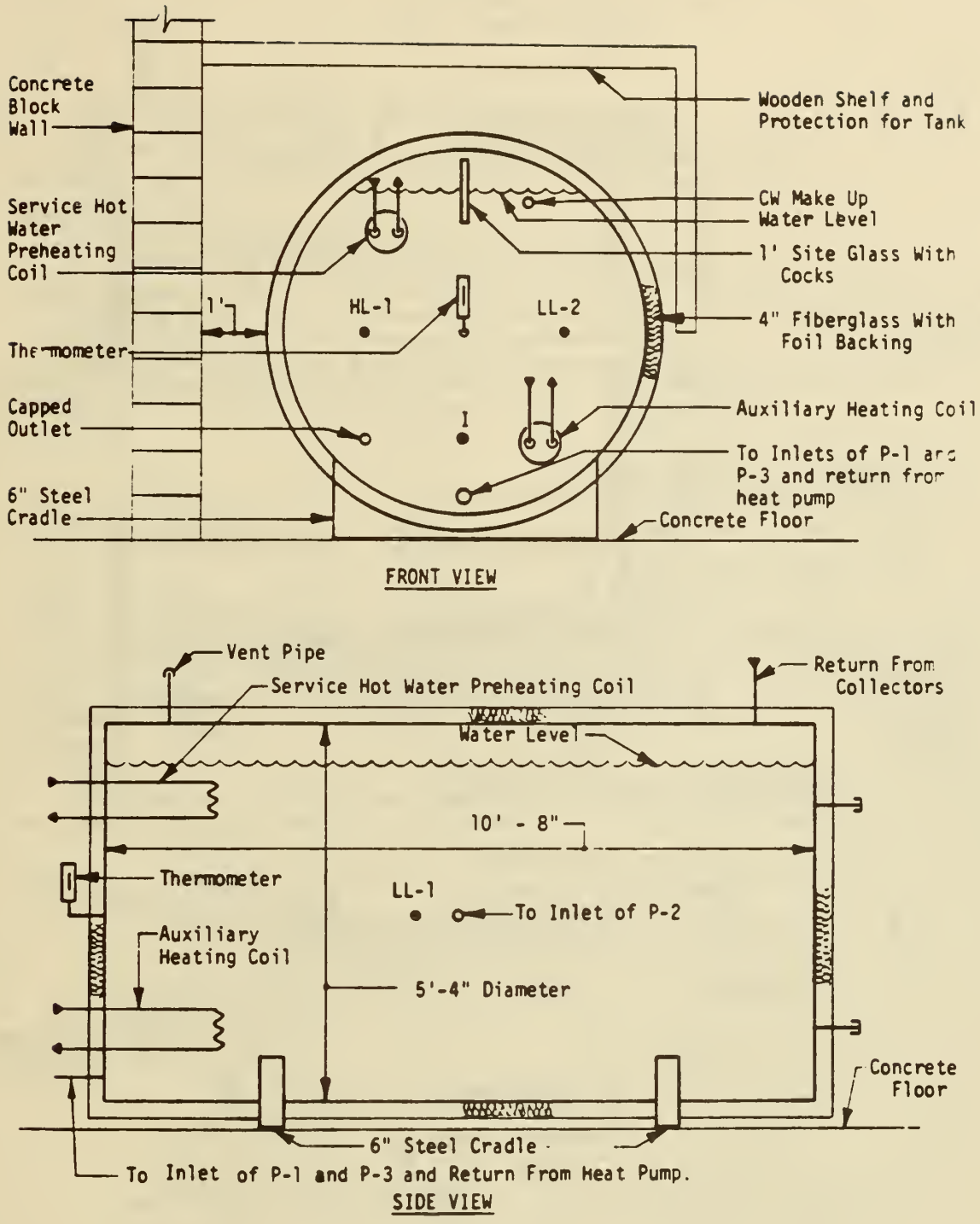


FIGURE V-21

Moseley Storage Tank

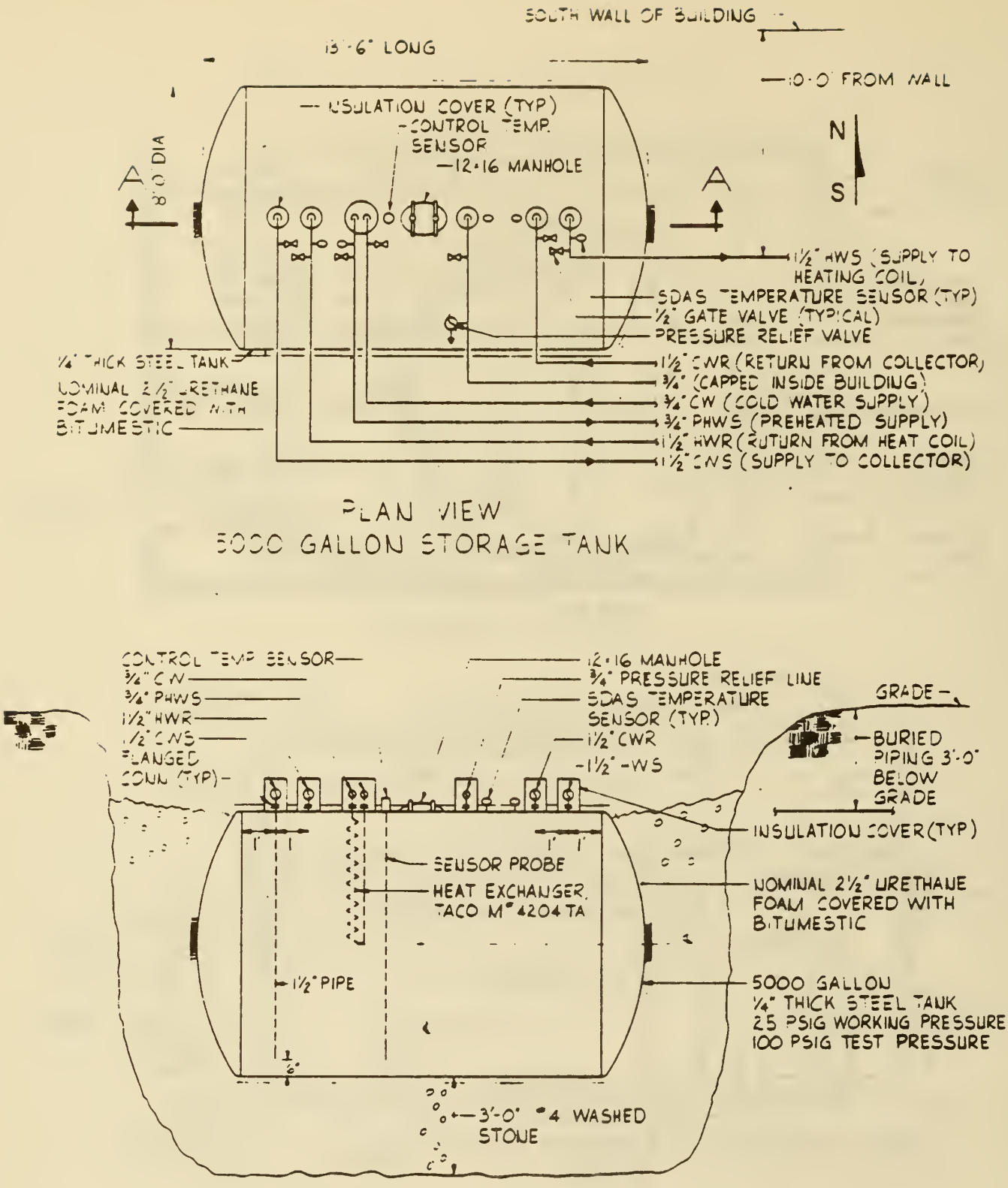
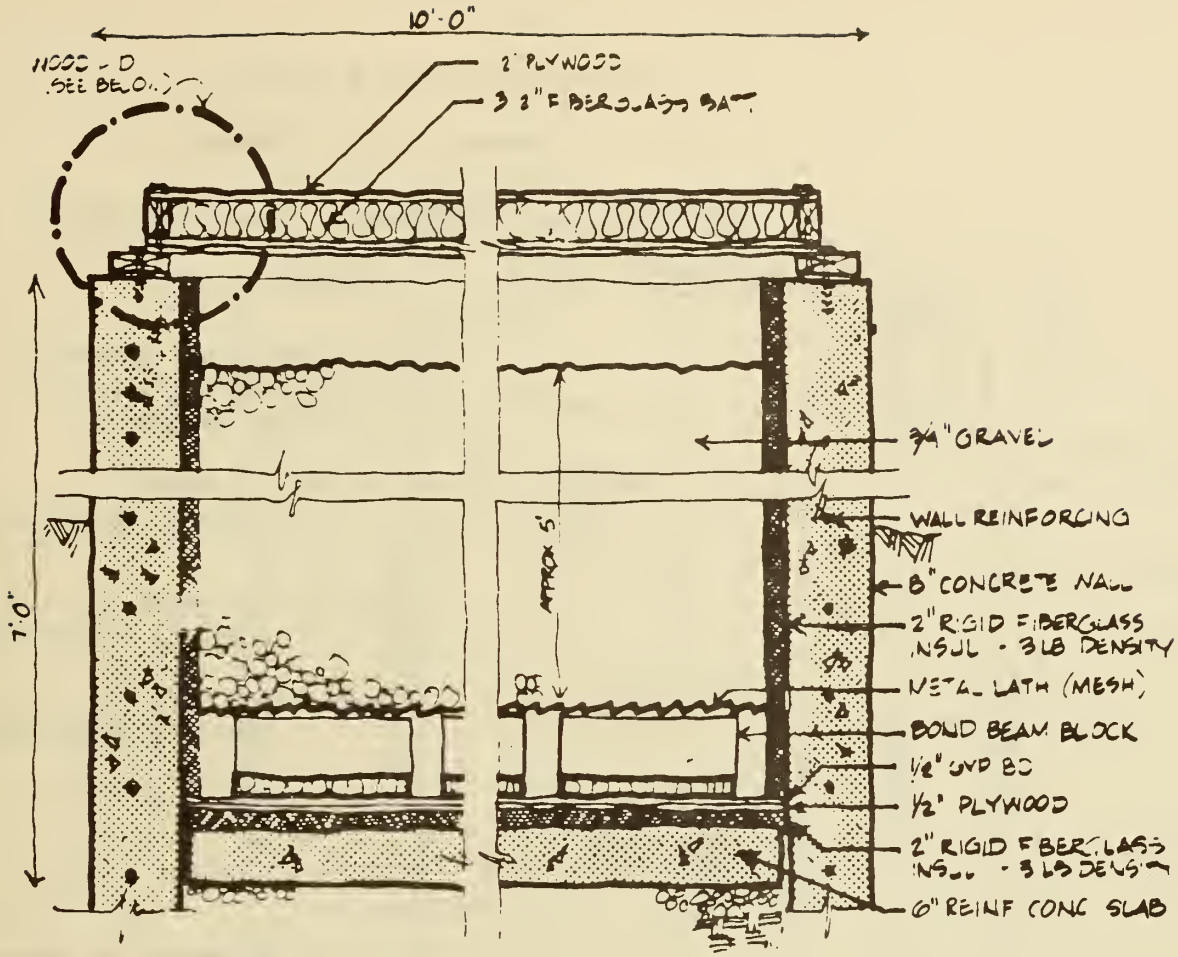


FIGURE V-22

Blakedale Storage Tank



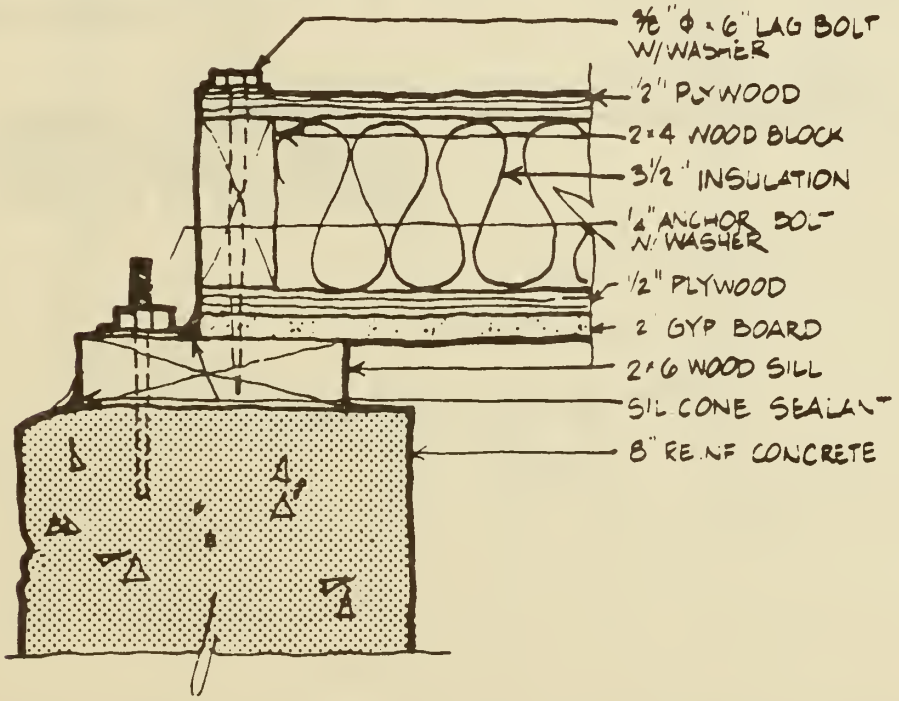


FIGURE V-23

Scattergood Rock Bin

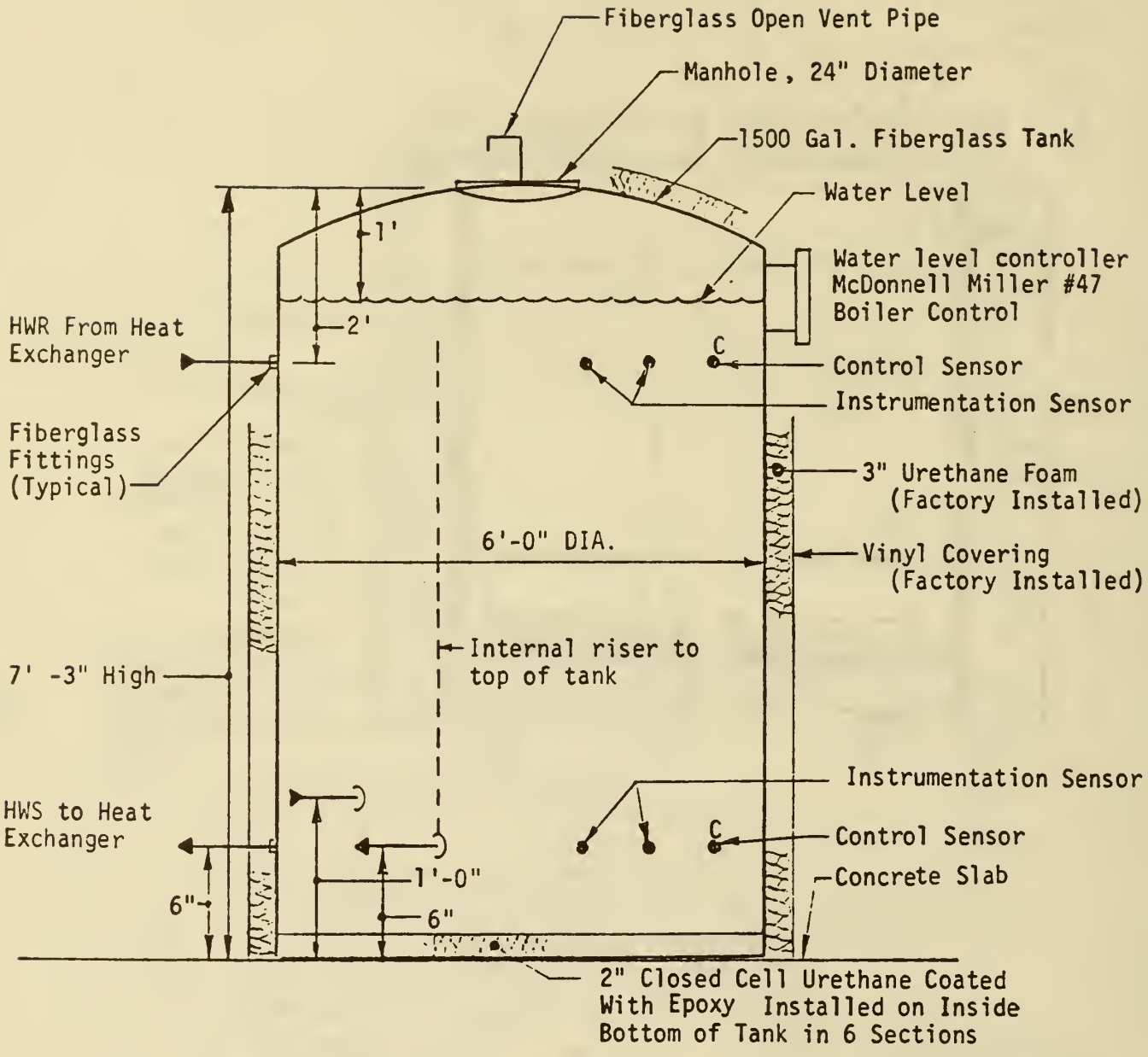


FIGURE V-24

Radian Storage Tank

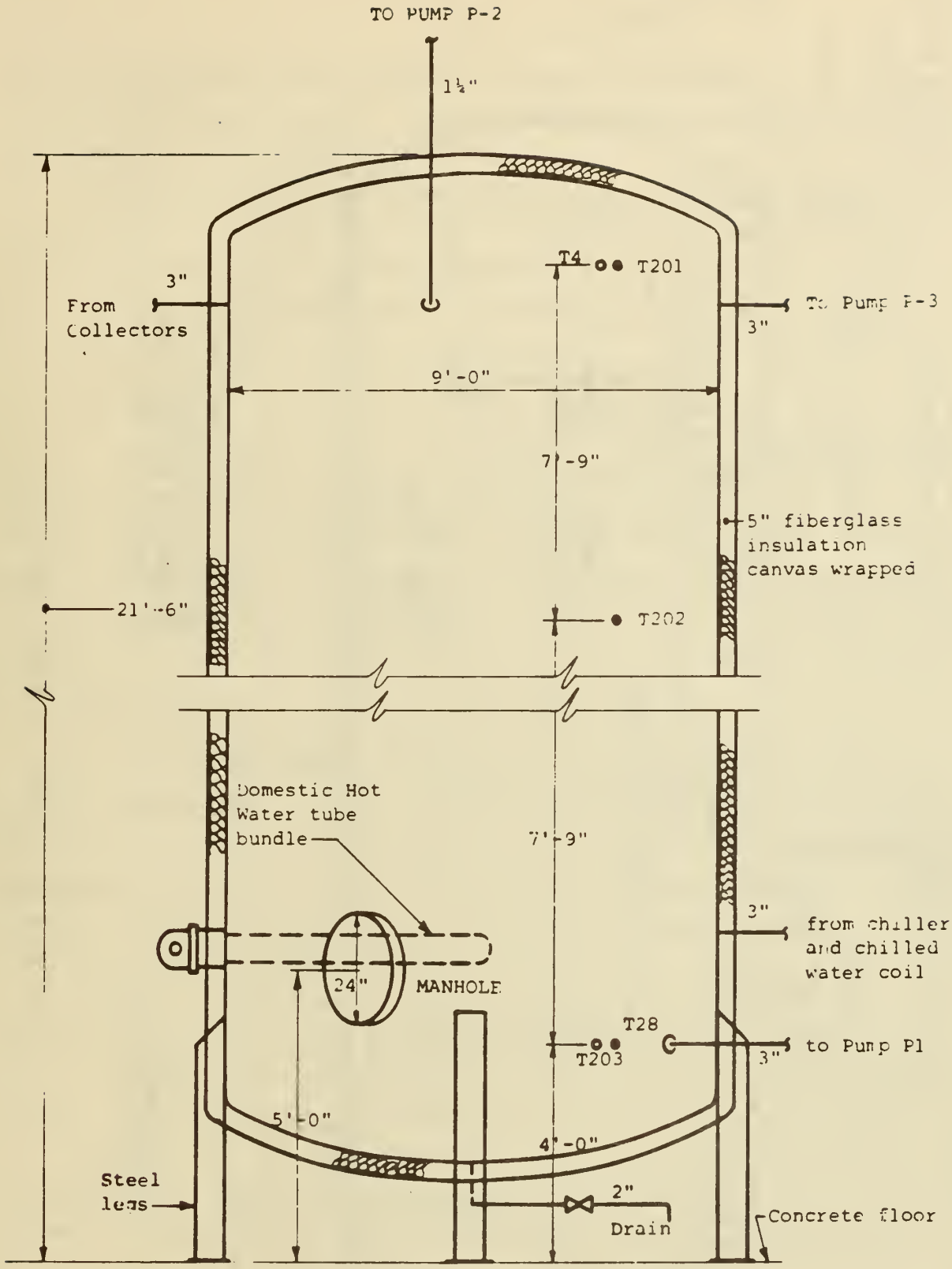


FIGURE V-25

Reedy Creek Hot Storage Tank, (Cold Tank Similar)

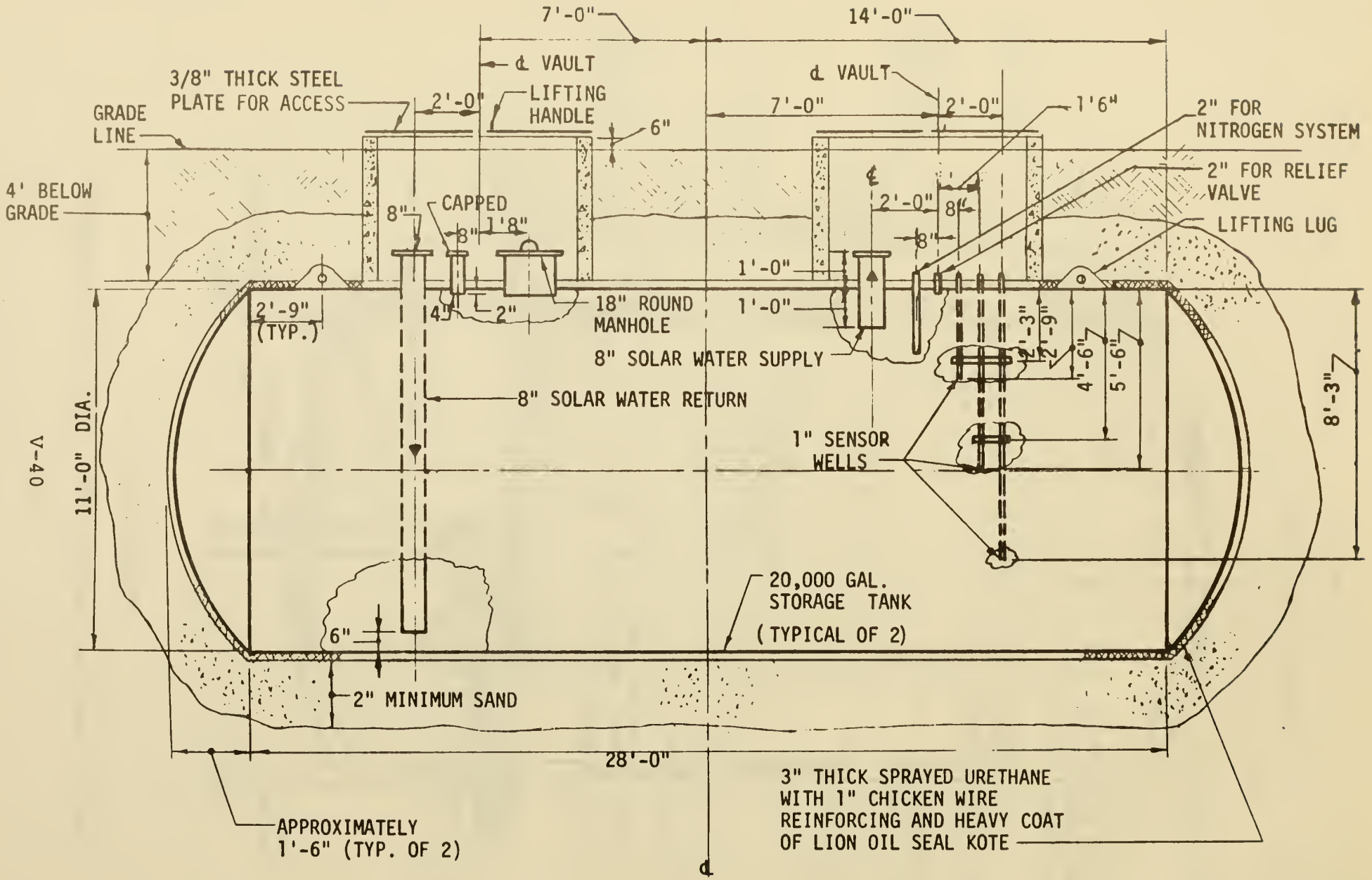


FIGURE V-26 Trinity Storage Task Detail

For the fiberglass tank systems (Aratex and Radian) the normalized storage materials and delivery costs average $3.60/ft^2 collector area and $1.10/gallon storage capacity.

Storage insulation costs show very good consistency in terms of percent of storage category total cost. Storage insulation costs average 26% of storage category cost.

Figure V-27 graphically summarizes the storage system unit costs for the ten projects.

F. ELECTRICAL AND CONTROLS CATEGORY

- Electrical Power System Costs

Table V-11 shows electrical power system costs for the ten systems. Costs vary from $0.20/ft^2 to $2.40/ft^2, at an average cost of $1.00/ft^2 or 2% of total system cost. Electrical power system costs average $0.30/ft^2 (1% of total system cost, for the process hot water system; $1.20/ft^2 or 3%, for the space heating systems; and $1.60/ft^2 or 1%, for the space heating and cooling systems.

- Controls System Costs

Controls systems costs are presented in Table V-12 Control costs vary from $0.60/ft^2 to $7.40/ft^2, at an average of $3.10/ft^2 or 5% of total system cost. Average cost for process hot water systems is $1.10/ft^2 or 3% of total cost; for space heating systems, $4.00/ft^2 or 7% of total cost; for space heating and cooling systems $4.30/ft^2 or 4% of total cost.

Perhaps a more meaningful cost representation to use is cost per controlled motor (pump or blower motor, automatic valve or damper motor). Controls system cost per controlled motor varies from $88/motor to $1657/motor, at an average of $715/motor.

However, if the two extremes in cost per motor controlled are not considered (Moseley and Trinity), the variation is reduced to between $323 and $912, with an average of $750/motor controlled.

- Electrical and Controls Costs Summary

Table V-13 summarizes electrical and controls costs. The combined costs of electrical and controls systems vary from $1.00/ft^2 to $8.50/ft^2, for the active systems, at an average of $4.20/ft^2 or 6% of total system cost. Figure V-28 summarizes the category unit costs.

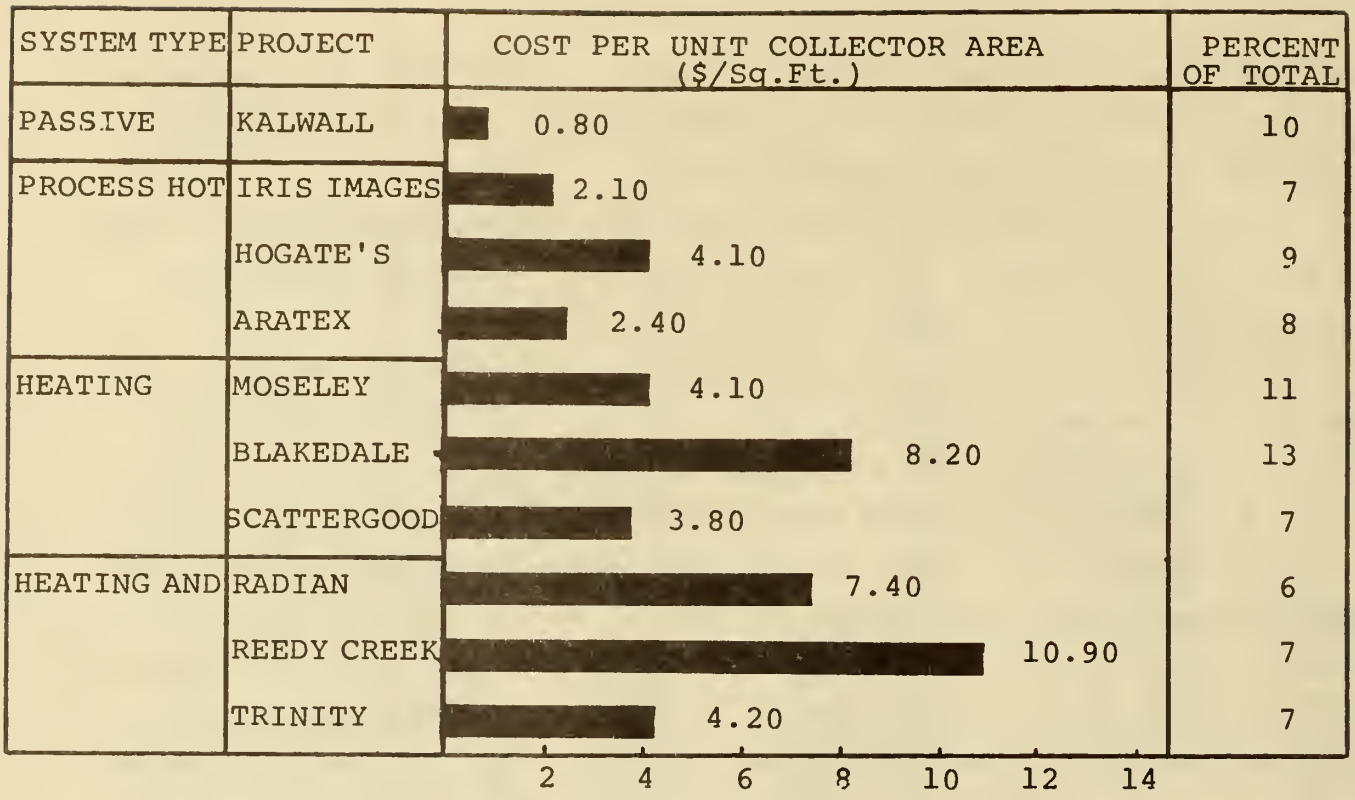


FIGURE V-27
STORAGE SYSTEM UNIT COSTS

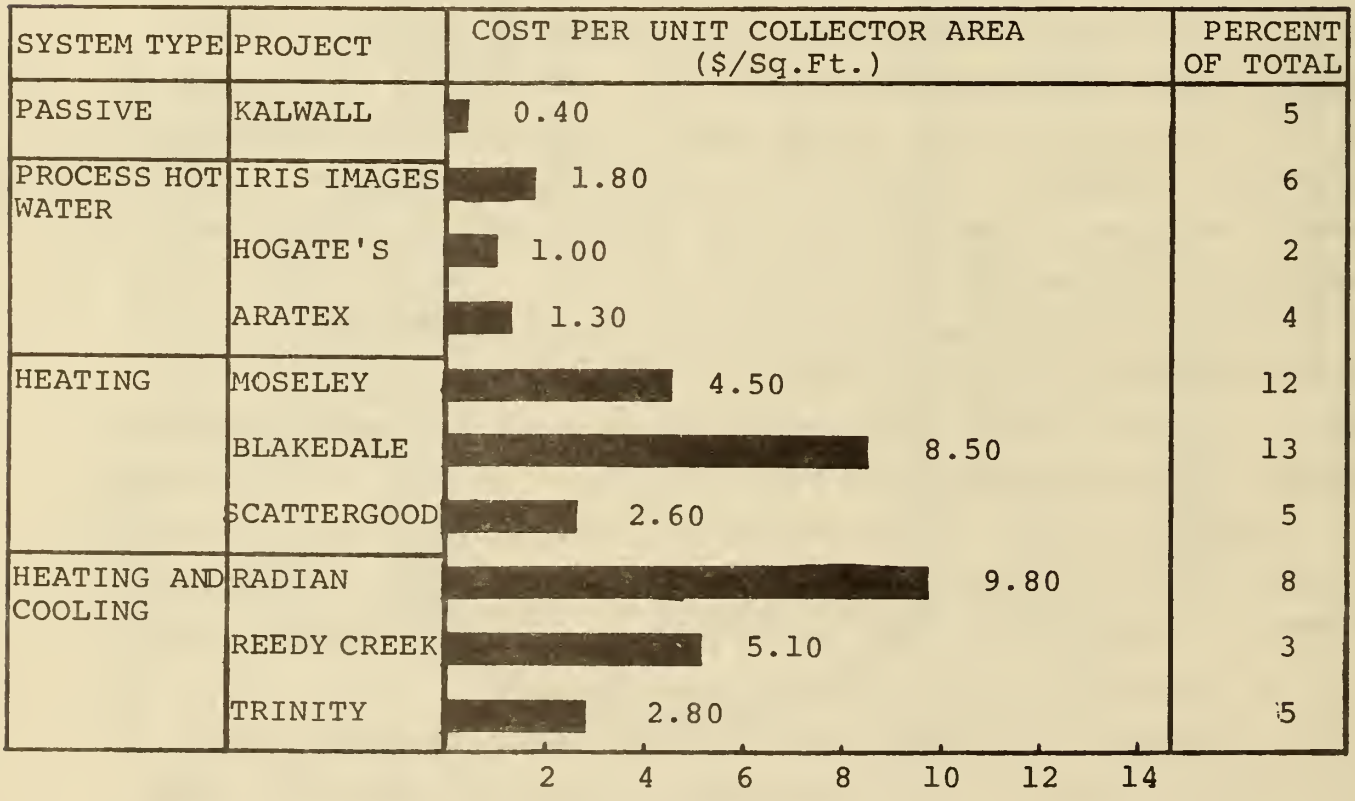


FIGURE V-28
CONTROLS AND ELECTRICAL SYSTEMS UNIT COSTS

TABLE V-11 ELECTRICAL COSTS

PROJECT	BARE COSTS AS REPORTED			BARE COSTS (1977 $'s)	GENERAL (G) OR SUB (S)	W/OH&P (1977 $'s)	COLLECTOR AREA (SqFt)	$/ SqFt	PERCENT OF TOTAL COST
	MATERIALS	LABOR	TOTAL						
KALWALL	255	285	540	580	S[G(255)]	680	1,750	0.4	4
IRIS IMAGES	a	a	110	120	S	130	600	0.2	1
HOGATES	a	a	2,100	235	G[S(1000)]	2,475	5,840	0.4	1
ARATEX	a	a	960	1,030	S	1,055	6,350	0.2	1
MOSELEY	a	a	550	590	S	650	376	1.7	5
BLAKEDALE	a	a	1,085	1,165	S[G(185)]	1,310	924	1.4	2
SCATTERGOOD	a	a	1,090	1,170	S[G(25)]	1,290	2,240	0.6	1
RADIAN	a	a	710	760	S	840	350	2.4	2
REEDY CREEK	a	a	6,340	6,340	S	6,975	3,840	1.8	1
TRINITY	a	a	9,375	10,070	S	10,315	15,633	0.7	1

a) Materials/labor breakdown could not be obtained.

TABLE V-12 CONTROLS COSTS

PROJECT	BARE COSTS AS REPORTED			BARE COSTS (1977 $'S)	GENERAL (G) OR SUB (S)	W/OH&P (1977 $'s)	COLLECTOR AREA (SqFt)	$/SqFt	PERCENT OF TOTAL COST	$/MOTOR CONTROLLED
	MATERIALS	LABOR	TOTAL							
KALWALL	a	a	a	a	a	a	1,750	a	a	a
IRIS IMAGES	140	565	705	755	G[S(110)]	930	600	1.6	5	465
HOGATES	1,600	1,500	3,100	3,100	G[S(1500)]	3,650	5,840	0.6	1	912
ARATEX	2,600	3,100	5,700	5,700	G	7,125	6,360	1.1	4	635
MOSELEY	670	120	790	850	G	1,060	376	2.8	7	88
BLAKEDALE	2,390	2,840	5,230	5,615	G[S(2,840)]	6,565	924	7.1	11	656
SCATTERGOOD	710	3,115	3,825	4,110	S[G(780)]	4,645	2,240	2.1	4	663
RADIAN	950	980	1,930	2,075	G[S(65)]	2,585	350	7.4	6	323
REEDY CREEK	b	b	11,565	11,565	S	12,720	3,840	3.3	2	909
TRINITY	b	b	35,000	35,000	G	34,800	15,633	2.2	4	1,657

a) Controls costs could not be separated from electrical category costs.

b) Materials/labor breakdown could not be obtained.

TABLE V-13 ELECTRICAL AND CONTROLS COST SUMMARY

PROJECT	ELECTRICAL W/O H&P (1977$/SqFt)	CONTROLS W/O H&P (1977 $/SqFt)	ELECTRICAL AND CONTROLS (1977 $'s/SqFt)	PERCENT OF TOTAL COST	COLLECTOR AREA (SqFt)
KALWALL	0.4	a	0.4	4	1,750
IRIS IMAGES	0.2	1.6	1.8	6	600
HOGATES	0.4	0.6	1.0	2	5,840
ARATEX	0.2	1.1	1.3	4	6,350
MOSELEY	1.7	2.8	4.5	12	376
BLAKEDALE	1.4	7.1	8.5	13	924
SCATTERGOOD	0.6	2.1	2.7	5	2,240
RADIAN	2.4	7.4	9.8	8	350
REEDY CREEK	1.8	3.3	5.1	3	3,840
TRINITY	0.7	2.2	2.9	5	15,633

a. Controls costs could not be separated from electrical costs.

G. HEATING AND COOLING EQUIPMENT

Table V-14 presents the heating and cooling equipment costs for the space heating and heating and cooling projects. Figure V-29 graphically summarizes the unit costs for this category. A significant unit cost savings appears between the 3-ton chiller equipment (Radian) and the 25-ton chiller equipment (Reedy Creek). The Trinity unit cost does not include the existing gas-fired absorption chillers. However, if the cost of a new chiller were added to the Trinity equipment category cost, the resultant total would approximate the Reedy Creek unit category cost.

H. GENERAL CONSTRUCTION

Table V-15 shows general construction cost information for the ten sites. General construction costs vary considerably from $\$0.10/ft^2$ to $\$10.30/ft^2$, at an average of $\$3.40/ ft^2$ or 4% of total system cost. The large variation in unit costs are due to the variety of cost components in the general construction category for each system.

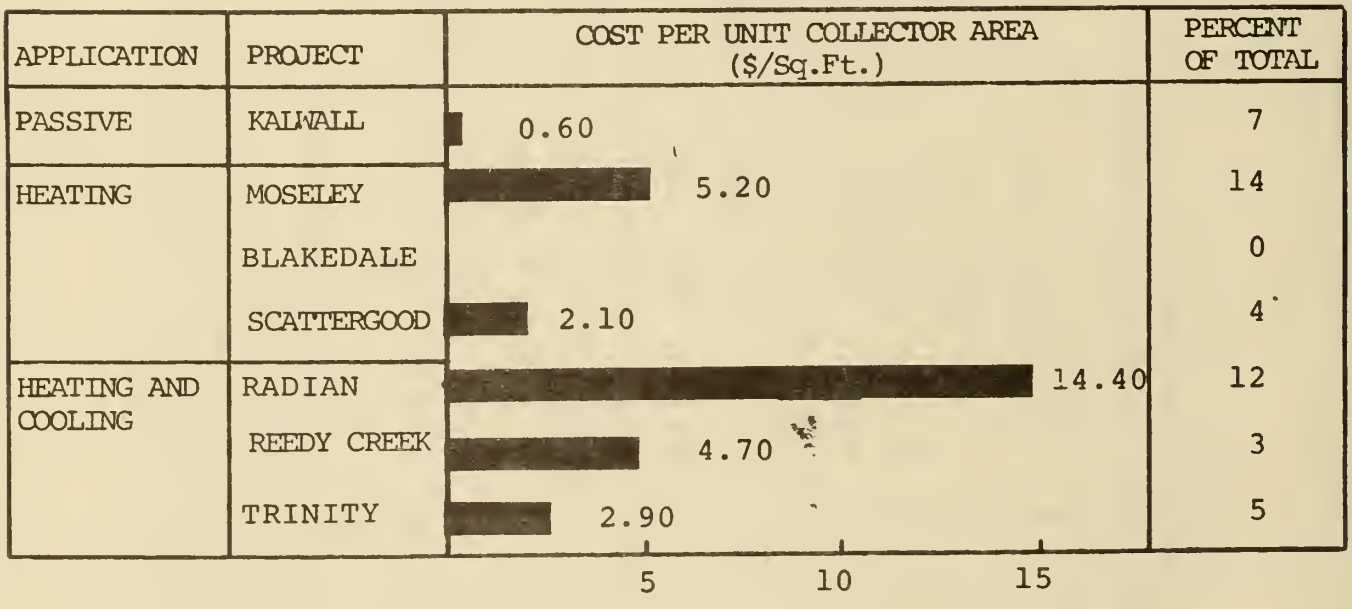


FIGURE V-29
HEATING AND COOLING EQUIPMENT COST

TABLE V-14. HEATING/COOLING EQUIPMENT COSTS

PROJECT	BARE COSTS AS REPORTED			BARE COSTS (1977 $'s)	GENERAL (G) OR SUB (S)	W/OH&P 1977 TOTAL	COLLECTOR AREA (SqFt)	$/SqFt	PERCENT OF TOTAL COST	EQUIPMENT INCLUDED	$/TON
	MATERIALS	LABOR	TOTAL								
KALWALL	365	400	765	820	S[G(365)]	965	1,750	0.6	7	Fans	---
MOSELEY	1,395	60	1,455	1,565	G	1,955	376	5.2	11	Heat Pump, HX's	---
BLAKEDALE	None	None	None	None	None	None	None	None	None	None	---
SCATTERGOOD	3,225	270	3,495	3,755	G	4,695	2,240	2.1	3	AHU, HX	---
RADIAN	3,625	120	3,745	4,020	G	5,030	350	14.4	12	Chiller, Air Handler Coil, Cooling Tower	1,676
REEDY CREEK	15,420	970	16,390	16,390	S	18,030	3,840	4.7	3	Chiller, HX	721
TRINITY	33,800	2,600	36,400	36,400	G	45,500	15,633	2.9	5	HX's	---

TABLE V-15 GENERAL CONSTRUCTION COSTS

PROJECT	BARE COSTS AS REPORTED	BARE COSTS (1977 $'S)	W/O H&P (1977 $'S)	GENERAL (G) OR SUB (S)	COLLECTOR AREA (SqFt)	$/SqFt	PERCENT OF TOTAL COSTS	DESCRIPTION
KALWALL	NONE	NONE	NONE	NONE	1,750	NONE	NONE	NONE
IRIS IMAGES	2,175	2,335	2,610	S[G(255)]	600	4.4	14	RENTALS, EQUIPMENT SPACE
HOGATES	17,400	17,400	19,565	S[G(2850)]	5,840	3.3	7	ARCH. PANELS, FENCE AROUND TANK, ROOFING, MISC.
ARATEX	5,110	5,110	6,390	G	6,350	1.0	4	PERMITS, FREIGHT, RENTALS
MOSELEY	220	235	295	G	376	0.8	2	RENTALS
BLAKEDALE	45	48	60	G	924	0.1	<1	RENTALS
SCATTERGOOD	465	500	550	S	2,240	0.2	<1	SITE WORK
RADIAN	1,240	1,330	1,665	G	350	4.8	4	WATER TREATMENT SYSTEM, RENTALS, MISC. LABOR
REEDY CREEK	32,735	32,735	39,530	G[S(9245)]	3,840	10.3	6	GENERAL CONTRACTOR SUPERVISION
TRINITY	48,005	48,005	56,220	S[G(22747)]	15,633	3.6	2	ROOF ACCESS, FENCE ROOFING, SCAFFOLDS, CLEANINGS

VI. TOTAL SYSTEM COSTS

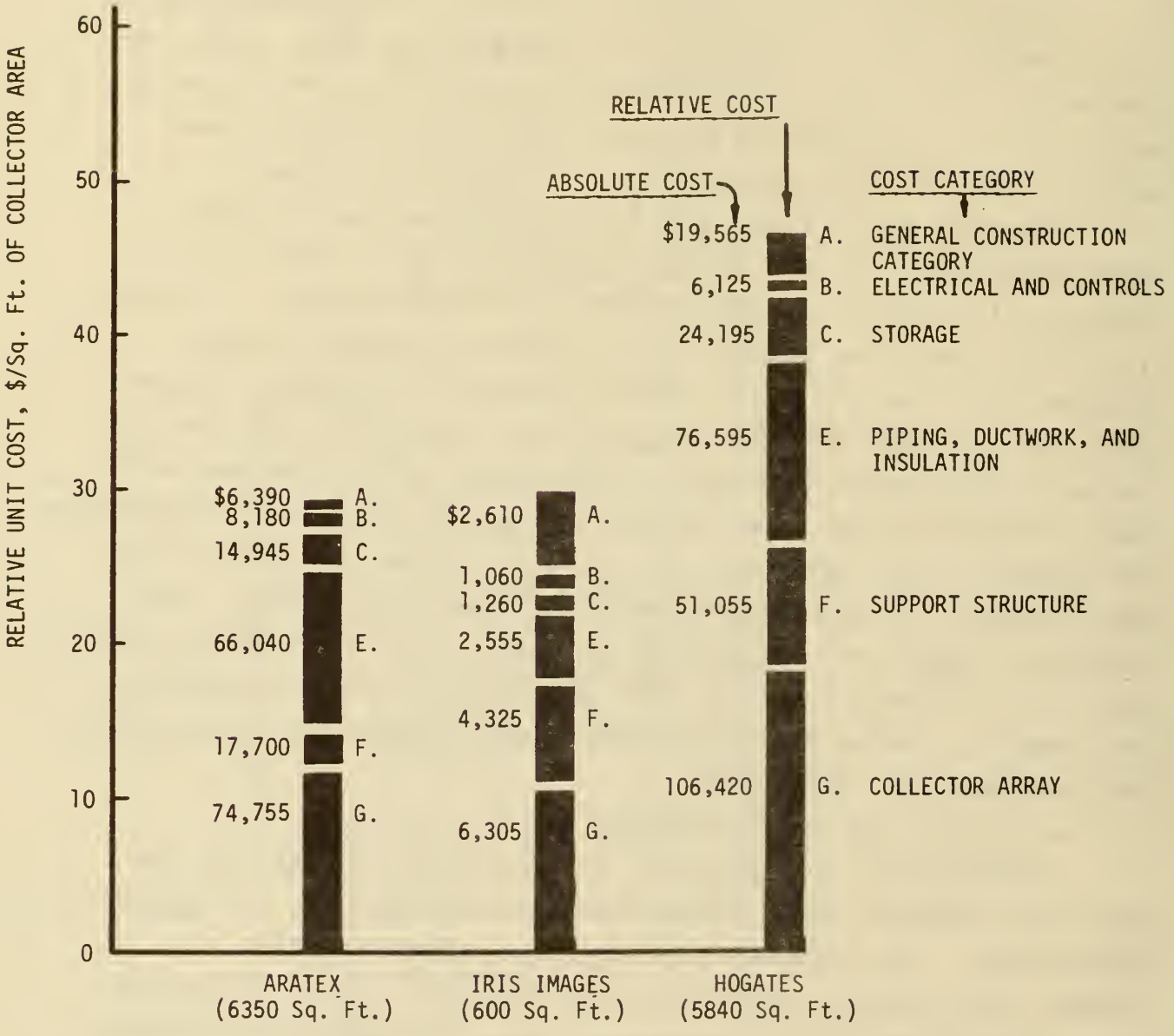
Section V presented and compared data category by category for the ten projects studied. This section presents and analyzes the total system costs which are the summation of the category costs. The previous sections are most useful for comparing individual category costs among different projects while this section should be most useful for analyzing the significance of all categories for individual projects.

Figures VI-1, VI-2, and VI-3 summarize the category cost breakdowns for the ten projects studied. Figure VI-1 presents the costs for the process hot water systems: Figure VI-2 for the three space heating and one passive system: Figure VI-3 for the three space heating and cooling systems. The vertical axis of each figure is the relative unit cost in terms of dollars per sq. ft. of collector area. The vertical bars are broken and labelled to illustrate their cost composition by category. In addition, the absolute value (in dollars) of the various categories appears to the left of the bars. The collector area (net effective) is listed below the name of the project. All costs are in 1977 dollars and include overhead and profit. Table VI-1 lists the total system costs in dollars and dollars per square foot.

- Process Hot Water Systems

Figure VI-1 illustrates the costs for the Aratex Industrial Laundry, Iris Images Photoprocessing Lab, and Hogate's Restaurant. The Hogate's system has a significantly higher total system unit cost than the other two. Aratex and Iris Images have nearly identical total system costs, although the composition of the costs is seen to vary significantly between the two. The collector costs for Aratex and Iris Images are comparable, and from the construction, one would expect the collector performance to be comparable. The Hogate's collector (double glazed, low iron glass, selective surface) is the highest performing flatplate collector of the systems studied and it has the highest collector cost.

FIGURE VI-1
TOTAL SYSTEM COSTS, PROCESS HOT WATER SYSTEMS
1977 DOLLARS W/OH&P



The Aratex system employed the simplest, lowest cost support structure of the systems studied. The designers took advantage of the flat roof, easy structural integration and lack of stringent aesthetic requirements to help reduce total system cost. Iris Images has two enclosed wooden frame support structures that blend with the building's architecture. The Hogate's support structure had to be incorporated into the building's complex roof structure; it had to be approved by the Fine Arts Commission for aesthetic impact; it had to support a large collector area in a limited space; and the installation of the system could not interfere with the operation of the restaurant.

Hogate's and Aratex demonstrate similar piping and insulation costs (there is no ductwork in these systems). The piping and insulation in these two was generally of the same quality, size, and extent. Iris Images, however, has piping that could appropriately be likened to residential sized systems. It has short runs of small diameter piping and as a result, the piping costs for Iris Images are less. The collector array piping was designed very differently on the Hogate's and Aratex systems although both have an equipment room located at one end of the roof, yet both systems had similar piping costs.

Storage system costs appear smallest for Iris Images, but this is because that system has the lowest ratio of gallons of storage to area of collector. Hogate's has the highest unit storage costs because it employs two ASME rated pressurized steel storage tanks, epoxy lined and R-27 fiberglass insulation with an aluminum sheathing. The Aratex system has a fiberglass tank with R-17 foam insulation and a metal jacket.

The electrical and control category costs are similar for all three projects and average $1.40 per square foot of collector area.

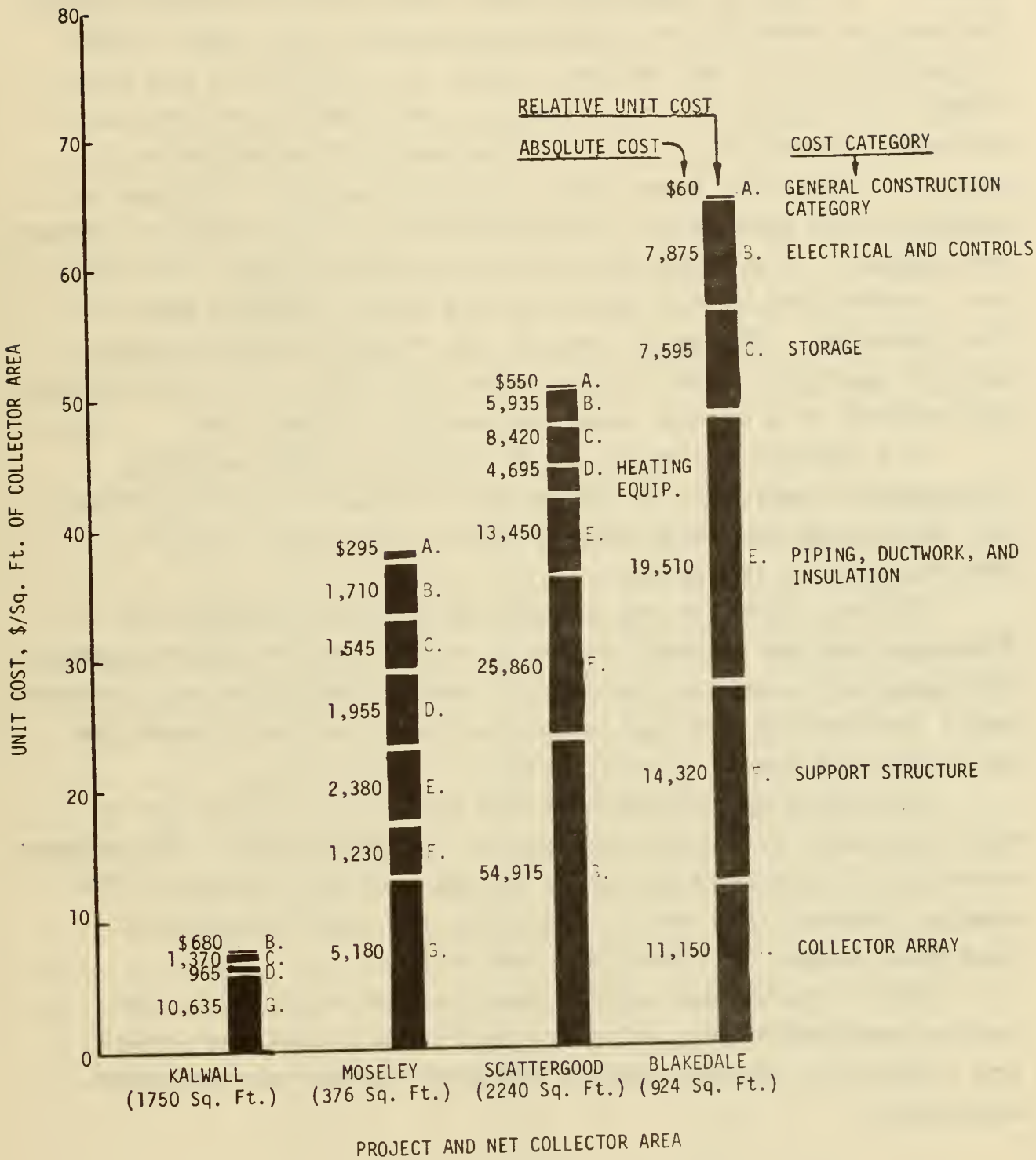
General construction costs are highest for Iris Images partly because a solar equipment space cost has been added since it was new construction. The Hogate's system is the most costly of the process hot water systems and it can be seen that except for the electrical and controls and the general construction categories, its costs are highest in each category. The high performance collectors, the intricate retrofit support structure and the well insulated storage tanks account for this fact. The Aratex and Iris Images total unit costs are nearly equal. The higher piping and insulation costs at Aratex are compensated for by the low support structure and general construction costs. At Iris Images, the higher support structure costs are compensated for by the lower piping and insulation, storage and collector costs.

- Space Heating and Passive Systems

Figure VI-2 illustrates the relative costs of the solar energy systems for the Kalwall Warehouse, the Terrell B. Moseley office building, the Scattergood School Recreation Center, and the Blakedale Professional Building. The Kalwall Warehouse is heated with a passive solar wall. The other systems are active solar systems. The Kalwall system is much lower in $/Sq.Ft. cost than the active systems.

Figure VI-2 indicates the highest cost for the collector category costs for Scattergood. The Blakedale collector costs may be somewhat misleading because they reflect the costs of collectors with aluminum absorber plates. However, these collectors were replaced by the manufacturer with collectors with copper absorber plates at no cost. The real collector cost could be expected to be higher. The Moseley collector was site-built by the owner/contractor. The collector category costs for that system (includes materials, assembly and mounting) can be seen to be comparable to manufactured collectors.

FIGURE VI-2
TOTAL SYSTEM COSTS, SPACE HEATING AND PASSIVE SYSTEMS
1977 DOLLARS, W/OH&P



The support structure costs are highest for the Blakedale system. It must be remembered that the support structure costs include the cost of the reflectors mounted on the back of two collector rows in this system. Also, the reflectors are not taken into account in the collector area figure, so that the Blakedale system is in effect "penalized" in an analysis of $/sq. ft. collector area. The Blakedale support structure is aesthetically integrated with the building and is made of redwood and cypress. The Scattergood School system support structure was manufactured by the makers of the metal building used as the gymnasium. The space beneath the support structure also acts as equipment room for the solar equipment. The collectors are mounted in a planar array against the tilted roof.

The support structure at the Moseley office building is somewhat lower than it might cost if built elsewhere because the owner used some available materials that could not be charged against the system.

Piping, ductwork and insulation costs are highest for the Blakedale system, largely due to extensive buried piping between the equipment room and the storage tank. The piping and ductwork costs for Moseley and Scattergood are similar even though one is an air and one is a water system.

Storage costs are highest for Blakedale largely due to the high ratio of gallons storage to collector area. The storage costs for Scattergood are for a 65 ton rock bin storage. The Moseley storage tank was an unpressurized lined steel tank with four inches of fiberglass insulation.

The Moseley water source heat pump shows up as a high heating equipment cost while the Scattergood equipment costs are relatively low and reflect the cost of the fans and heat exchangers.

The electrical and controls cost are highest for Blakedale of all the systems studied. Small general construction costs are included on all the active space heating systems.

The total cost for Blakedale is the highest of these systems and it can be seen that except for the collector array and heating equipment the Blakedale system is highest in every category. The Scattergood system has the highest collector array cost of flat plate systems studied and its support structure is relatively expensive. The Moseley system total cost appears to consist of moderately priced cost categories, among which none can be singled out as obvious areas for cost reduction in similar installations. The Kalwall system, of course, is much lower in cost and consists largely of the collector array costs.

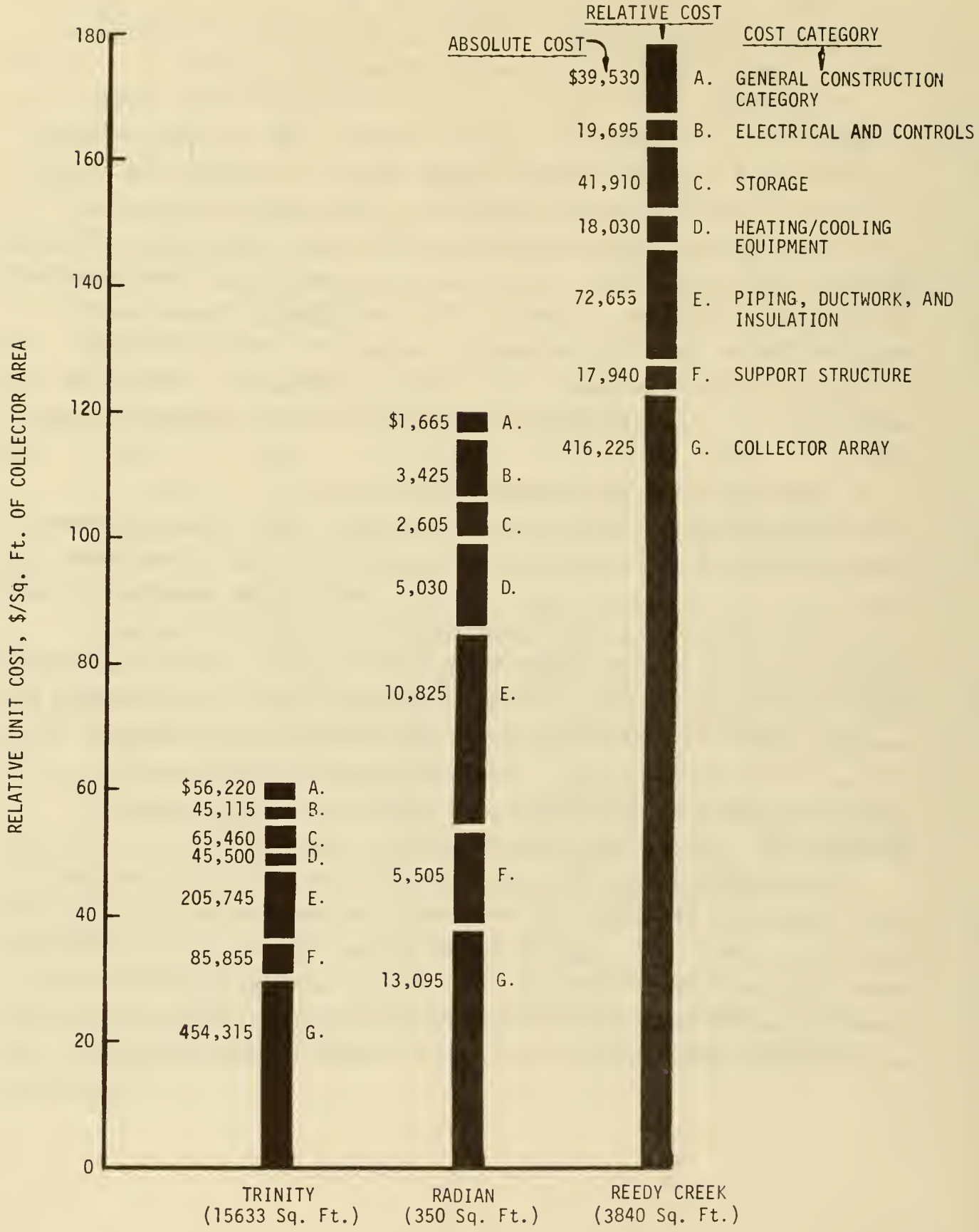
- Space Heating and Cooling Systems

Figure VII-3 summarizes the category cost breakdowns for Trinity University Central Plant, Radian Corporation Office Building, and the Reedy Creek Utility Co. Office Building.

Upon inspection, the most obvious factor is the unit collector array costs at the Reedy Creek site. These innovative focusing collectors which incorporated the concentrating troughs into the roof structure experienced cost overruns during their manufacturer. The Trinity and Radian systems employ the same fresnel lens collector but a significant difference in unit cost exists between them.

The aluminum angle support structure at Radian was the most expensive of these three systems and had relatively high materials cost. The support structure at Trinity was galvanized steel and was less expensive on a unit cost basis. The Reedy Creek support structure was simply the specially fabricated metal pieces that formed the ends of the collector troughs.

FIGURE VI-3
TOTAL SYSTEM COSTS, SPACE HEATING AND COOLING SYSTEMS
1977 DOLLARS, W/OH&P



The piping insulation and ductwork costs are highest for Radian, the smallest sized systems. The Radian cost includes a ductwork distribution system. Economies of scale (large systems costing less per unit area) may be responsible for the piping and insulation cost trends between Reedy Creek and Trinity.

The Trinity system used existing chillers which were not charged against the solar system. In a new system, the heating and cooling equipment cost category would be higher. The equipment category indicates a significant economy of scale effect when going between a 3 ton (Radian) cooling system and a 25 ton (Reedy Creek) cooling system for heating and cooling equipment.

Storage costs are highest for Reedy Creek due in large measure to the storage insulation cost. Trinity had very low storage insulation costs and low total storage cost. Radian, which has a fiberglass tank exterior to the building, also had low storage costs.

Electrical and controls costs are highest for Radian, second highest for Reedy Creek and lowest for Trinity. Again, this may be due to the economies of scale.

The Trinity system was lowest total cost and lowest in each category except the support structure. The Radian system was highest in the support structure, piping, insulation and ductwork, equipment, and electrical and controls categories. The Reedy Creek system costs were dominated by the high collector costs, but exhibited high general construction and storage costs.

TABLE VI-1 TOTAL SYSTEMS COSTS

PROJECT	TOTAL COST (1977 $'s, W/OH&P)	TOTAL UNIT COST $/SqFt
KALWALL	13,650	7.80
IRIS IMAGES	18,115	30.20
HOGATES	283,955	48.60
ARATEX	188,015	29.60
MOSELEY	14,295	38.00
BLAKEDALE	60,510	65.50
SCATTERGOOD	113,825	50.80
RADIAN	42,150	120.40
REEDY CREEK	625,985	163.00
TRINITY	958,210	61.30

VII. CONCLUSIONS

This section presents the conclusions that have resulted from this study that have implications beyond the ten sites. As previously stated, these ten sites were not selected on the basis of their representativeness and ten sites are a very limited sample from which to draw conclusions. Nonetheless, some apparent trend data can lead to reasonable preliminary conclusions.

A. THE METHODOLOGY

The following conclusions regarding the methodology have evolved.

- The level of detail of cost data that can be obtained from a project is limited.
- A level of cost data detail significantly more precise than that utilized in this study is not practical.
- Not all data points desired will be separately identified at each site.
- Very useful data can be collected with a reasonable effort when the level of detail requested conforms with standard industry practice.
- Total project construction cost has been obtained in each site studied to date, thus it is reasonable to expect to obtain aggregated project cost data.

B. MAJOR COST FACTORS

At the beginning of this study, it was determined that a number of cost factors should be investigated to establish the extent and type of impact that they had on solar system construction costs. It was realized at that time that many systems would need to be analyzed before definitive impacts could be quantified. However, on the basis of the few systems studied to date, some judgements regarding cost factors can be made. The following cost factors are divided into general and subsystem factors for discussion. Obviously this list cannot be exhaustive.

- General
  - o The Designer

By far the greatest single factor that affects final system cost is the designer's perspective. At each decision

point in the design process, the designer makes cost/performance and cost/quality trade-offs. The designer will often either take the attitude of maximizing system efficiency with cost a secondary consideration or he will attempt to keep costs to a minimum with performance secondary. It is one objective of the National Solar Data Program to help provide the cost and performance data that will enable designers to optimize the cost/performance trade-offs to obtain systems that they believe will be reliable, durable and will not degrade excessively in performance for a reasonable system life and cost. The critical points in systems that require expensive, high quality equipment must be identified.

o System Complexity

System complexity is another aspect of the system design that has significant cost impacts. Each extra mode of operation adds cost and makes it more difficult to obtain a reliable system. Complex systems can be made reliable but they will be more expensive. Each extra control mode should be justified on a cost/performance basis. System complexity will usually add costs in the following areas:

- Controls and electrical
- Piping
- Insulation
- Ductwork
- Start-up and de-bugging
- Maintenance

o New vs Retrofit

The integration of the solar energy system into the building is not always easy. While it was not possible as a result of this study to say that systems installed in new buildings were less expensive than systems retrofitted into existing buildings, it was possible to identify where costs were higher in some systems for some cost categories because they were retrofit. Generally, these added costs could be found in the piping, ductwork and support structure categories. However, it is also possible to identify higher costs in some new buildings because of non-optimum equipment placement and structures

necessitating longer pipe runs and more elaborate collector support structures.

- o Taxes

Most of the contractors for the projects visited had to pay state sales taxes on the construction materials they purchased for the solar energy systems as they do for all construction projects. Most frequently, these taxes were 4% of the selling price of the materials. These taxes effectively added several percent to the total cost of the system.

- o Construction Delays

Only one of the projects studied, Reedy Creek, had encountered construction delays beyond those that could be expected for typical non-solar type construction. At Reedy Creek, the delay was associated with manufacture of the collector. In general, construction delays were not a cost factor.

- o Union/Non-Union Labor

At Reedy Creek, labor jurisdictional areas were agreed in advance of construction. The Ironworkers installed the focusing panels and the Pipefitters installed the collector tubes. However, a union agreement required field fabrication of the collector manifold that the designers had anticipated performing in the manufacturing plant. The on-site fabrication added significantly to the system cost.

No other jurisdictional problems were identified with the systems studied. There appeared to be no obvious correlation between cost and type of labor.

- o Size of the Project

Though many other cost factors tend to mask the impact of the system size on the project cost, there are several categories in which the unit cost can be expected to decrease with system size. Collector manufacturers often give discounts for large purchases of collectors. Installers tend to install the later collectors in a large array more quickly than they are able to install the first collectors. In a small system, by the time an installer has learned how to install the collectors correctly and quickly, he is finished. The comparison

of the collector array costs for Trinity and Radian point out the possible extent of these factors.

The heating/cooling equipment category also enjoys some economy of scale. It appears that a significantly large difference in unit costs exists between 3-ton and 25-ton absorption chillers (Radian and Reedy Creek).

Electrical and controls category unit costs tend to decrease in systems of the same type (i.e. hot water, heating, or cooling) as the system size increases. More definitive assessment of economies of scale will require the analysis of more systems.

o Geographic Area

Various engineering cost estimating guide books provide city cost indexes which enable the designer to estimate the impact of project location on cost. The figures presented in Table VIII-1 are taken from the Means Mechanical & Electrical Cost Data 1978 and illustrate the relative factors for materials, installation and total costs for mechanical systems.

The cities listed are for either the city in which the respective project is located or the closet city for which the reference had information. It is obvious from inspection of this table that materials costs vary little around the country while installation (labor) costs can vary by 95% (San Francisco versus Columbia, S.C.); for typical building mechanical systems the total cost index varies by about 40%. The costs presented in this report have not been normalized to account for regional variations. Future analyses should include a more detailed assessment of the importance of this factor.

o Contractual Instrument

The general contractor's overhead and profit were removed from the data for the projects studied and a constant value of overhead and profit were added. This had the effect of removing to a large degree the impact of the contractual configuration upon project cost. For instance, the use of construction management for projects instead of hiring a general construction contractor could offer potential savings since a lower factor is applied to the subcontractor's costs and the

TABLE VII-1
CITY COST INDEXES FOR MECHANICAL SYSTEMS TAKEN FROM
MEANS MECHANICAL AND ELECTRICAL COST DATA 1978

PROJECT	LOCATION	INDEX		
		MATERIAL	INSTALLATION	TOTAL
KALWALL	Manchester, NH	100.0	83.0	91.3
IRIS IMAGES	Mill Valley, CA	100.1	134.0 (San Francisco)	117.4
HOGATES	Washington, D.C.	101.9	93.7	97.7
ARATEX	Fresno, CA	97.0	116.8	107.1
MOSELEY	Lynchburg, VA	100.2	75.6 (Roanoke)	87.7
BLAKEDALE	Greenwood, SC	100.0	68.7 (Columbia)	84.0
SCATTERGOOD	West Branch, IA	99.7	85.3 (Davenport)	92.6
RADIAN	Austin, TX	99.9	80.2	89.8
REEDY CREEK	Lake Buena Vista, FL	98.3	80.6 (Orlando)	89.2
TRINITY	San Antonio, TX	99.7	85.4	92.4

bare costs. Also, the prepurchasing of major equipment items by the owner can sometimes save the owner the general contractor's mark-up on major equipment like the collectors. In the report, pre-purchased equipment is treated the same as the general contractor's direct costs.

- Subsystems
  - o Collector Array

Seven of the ten systems studied had collector array costs that were between 30 to 50% of the total systems costs. The flat plate collector array costs varied between $10.50 and $24.50 per square foot. The focusing collector costs were significantly higher. Mounting costs for the collectors varied from $0.30 to $8.70 per square foot. Seven of the ten systems experienced collector mounting costs between $1.20 and $4.90.

An effort by the designer to select collectors that require little mounting time could result in a savings of several dollars per square foot. Site-built collectors cost less for materials but the installation labor can be expected to be higher than for a typical manufactured collector. Careful alignment is critical to the installation of some collectors and can add to the time required. Cherry pickers or small cranes were used successfully in several sites to place the collectors on the roof inexpensively.

o Support Structure

A review of the costs for the support structure for these ten systems indicates that requiring the support structure to perform other functions than simply supporting the collectors could add $5.00 to $10.00 per square foot of collector to the cost of the system, which is not a trivial amount. The systems that could be considered to have multiple purpose support structures in this study are: Iris Images, Hogate's, Blakedale, Scattergood and Reedy Creek.

Some of the other functions that can be performed by the support structure are:

- Improve the aesthetic or architectural integration of the collectors into the building.

- House equipment
- Provide reflectors
- Form part of the building roof structure
- Form part of the building weatherproofing

It may be better to hide the collectors from view if appearance is a great concern and an inexpensive method of enhancing the appearance of the collectors cannot be found.

The extra cost of the support structure to provide the other functions must be weighed against the savings involved in reducing costs in other areas.

o Piping, Ductwork, and Insulation

Major factors identified as impacting the cost of the energy transport subsystem are the length of runs between major system components, underground piping, the importance of appearance of the finished piping, and complexity of the system. The costs for these categories in the ten systems studied varied from $4.00 to $30.00/square feet. The percentage of the total system cost ranged from 11% to 36%. There are not enough data points to determine if system size or new versus retrofit installation are significant cost factors.

o Storage

Potential savings in some of the systems studied could have been achieved without significantly decreasing performance by reducing storage valume.

The storage container also is an important cost factor in this category. The least expensive water storage container is a non-pressurized steel tank, followed by fiberglass tanks and then pressurized steel tanks. The storage subsystems represented between 6 and 13% of the total system cost for the studied systems. In light of the recognized importance of the storage subsystem to the overall system performance, storage does not appear to be an area where costs should be skimped. However, good materials and installation procedures are probably more important than added storage volume.

- Controls and Electrical

Controls and electrical costs varied between $0.40 and $9.80 per square foot of collector area and represented between 2 and 13% of the total system cost.

There were no observable trends in the controls and electrical costs among the ten systems.

A continued program of cost data collection and analysis on other demonstration projects will permit more definitive evaluation of all these cost factors.

APPENDIX: SYSTEM DESCRIPTION SUMMARIES

The brief description of each site provided below is taken from the Executive Summary chapters and selected drawings of Solar Project Description documents prepared for the sites. The order in which the site descriptions are presented is also used in presenting cost information. Sites are broken down into application categories: Passive, Process Hot Water, Space Heating, and Space Heating and Cooling. In each category, sites are listed in order of increasing collector area.

A. PASSIVE

- KALWALL WAREHOUSE (SEE FIGURES A-1 AND A-2)

The following is a brief summary of the Kalwall Corporation's solar heated warehouse demonstration project. Highlights of this site include:

- o COLLECTOR TYPE: Passive wall
- o FREEZE PROTECTION: None required
- o APPLICATION: Heating
- o STORAGE TYPE: Concrete floor and warehouse contents
- o NEW OR RETROFIT: Retrofit
- o INSTRUMENTED FOR PERFORMANCE EVALUATION: Yes

The direct gain passive solar system was retrofitted to a 10,000 square foot warehouse section in Manchester, New Hampshire. The design used 1750 square feet of Kalwall Corporation's Sunwall Solar Window as the sourth wall collector aperture. The warehouse's concrete slab floor and inventories provide thermal storage. Five 24-inch, thermostatically controlled fans are used for heat circulation. Auxiliary heat is provided by two space heaters supplied with hot water from an oil-fired boiler.

The solar system has been fully instrumented for data acquisition and is included in the National Solar Data Network.

B. PROCESS HOT WATER

- IRIS IMAGES PHOTOPROCESSING LABORATORY (SEE FIGURE A-3 AND A-4)

The following is a brief summary of the Iris Images, Inc. solar installation. Major features of this system include:

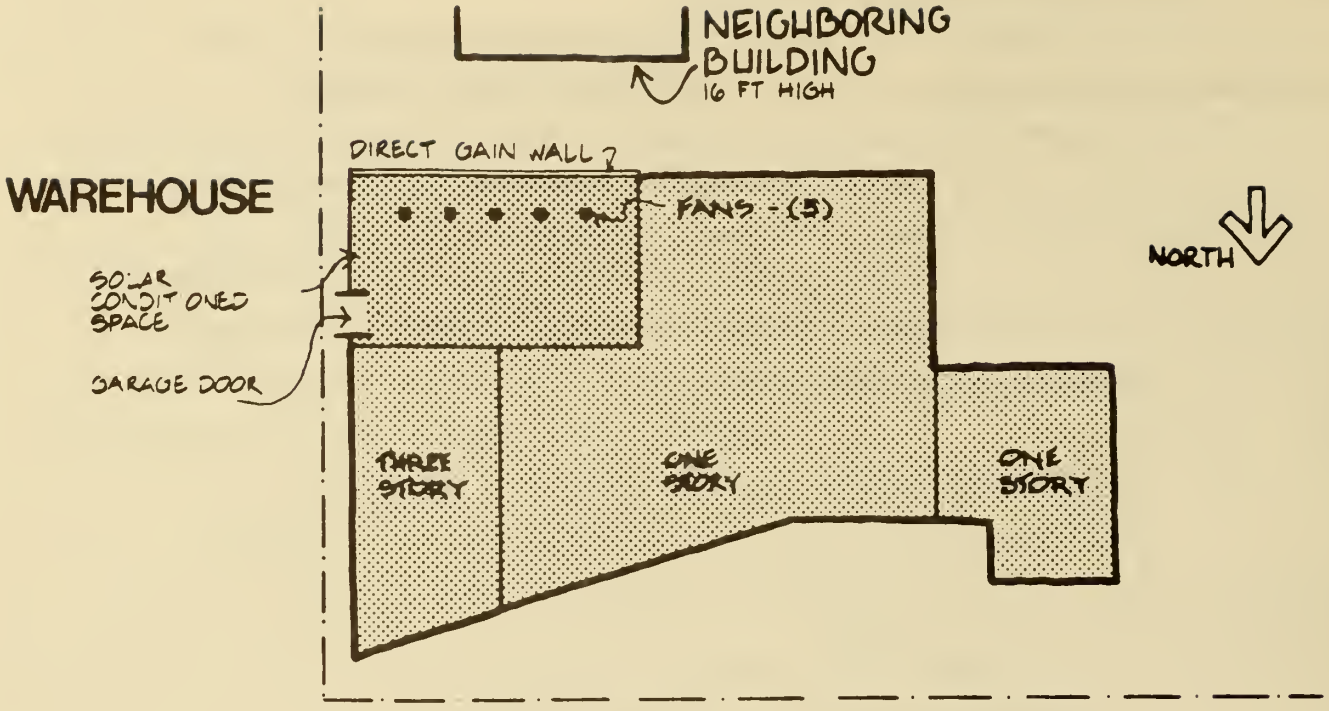


Figure A-1
Kalwall Site Plan

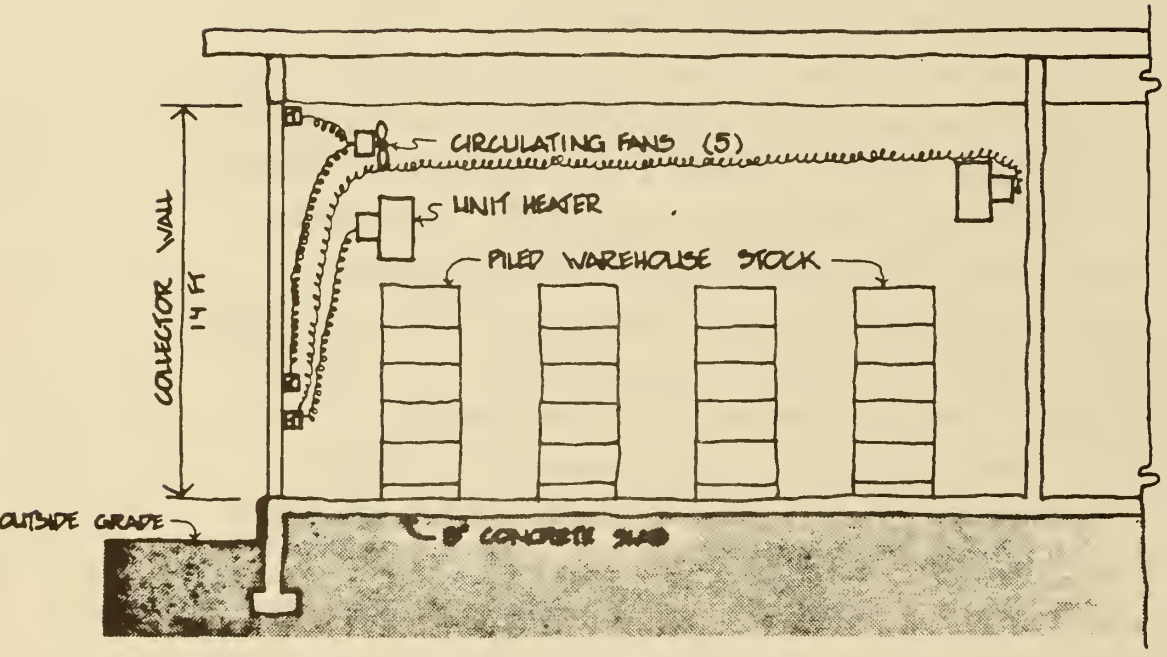


Figure A-2
Kalwall Building Section

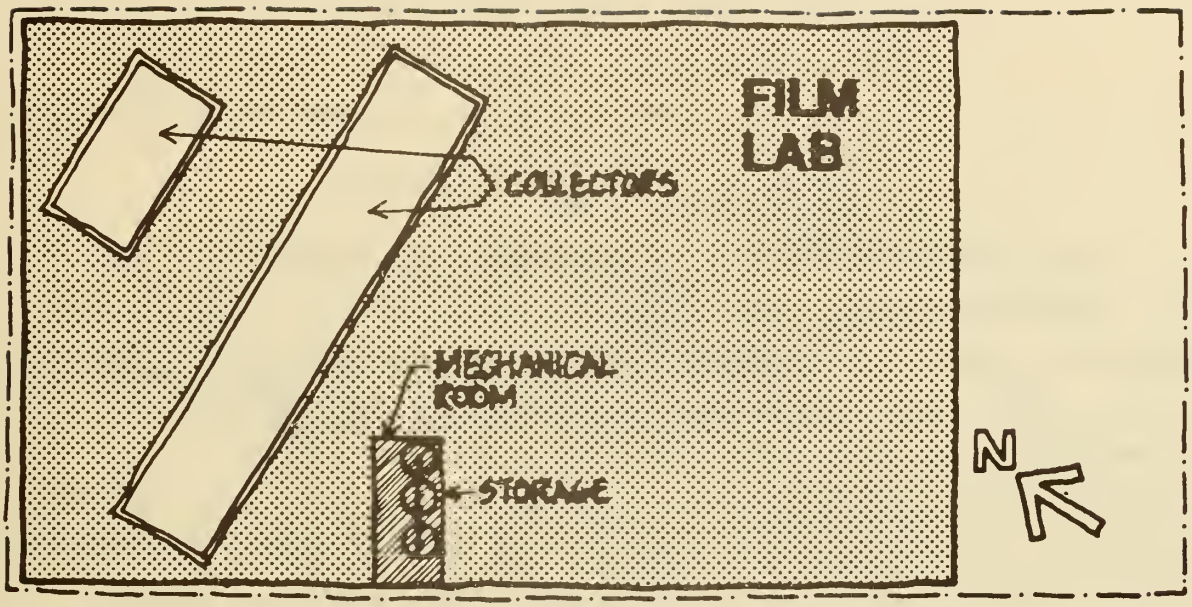


Figure A-3
Iris Images Site Plan

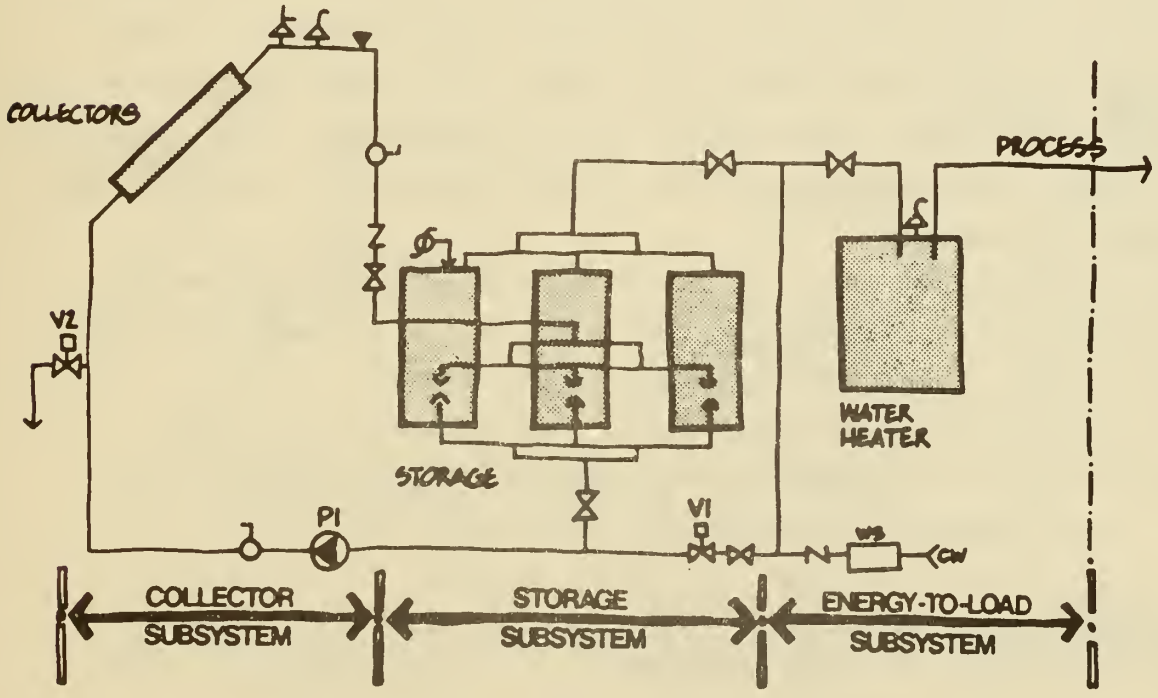


Figure A-4
Iris Images Schematic

- o COLLECTOR TYPE: Flat plate, Liquid
- o FREEZE PROTECTION: Circulation, Draindown
- o APPLICATION: Photographic process water heating
- o STORAGE TYPE: Interior tank
- o NEW OR RETROFIT: New
- o INSTRUMENTED FOR PERFORMANCE EVALUATION: Yes

The solar energy is used to heat photographic process water in a commercial photo-processing laboratory located in Mill Valley, California. The solar system was installed in the new building during the Spring of 1976.

The two collector banks are mounted on the flat roof of the building with a total aperture area of 600 square feet. Both of the collector banks were site fabricated. The absorber plates for one bank are aluminum, as manufactured by Sunburst Solar Energy, Inc. The other absorber plates are copper and were manufactured by Solar Development, Inc. Copper tubing is used for the fluid passages in both collectors.

Both collector banks are connected in parallel with rigid connectors and three 120 gallon insulated tanks located on the floor of the upper level mechanical room. All ancillary equipment and controls are also located in the mechanical room near the storage tanks. None of the piping in the equipment room has been insulated to date.

Softened cold water is first preheated and then flows to the auxiliary heater. Auxiliary heating of the process water is provided by a gas fired storage type water heater.

The solar system has been fully instrumented for data acquisition and is included in the National Solar Data Network.

- HOGATE'S RESTAURANT (SEE FIGURES A-5 AND A-6)

The following is a brief summary of the Hogate's Restaurant solar installation. Major features of this system include:

- o COLLECTOR TYPE: Liquid, Flat plate
- o FREEZE PROTECTION: Anti-freeze
- o APPLICATION: Restaurant, service water heating
- o STORAGE: Liquid, Exterior

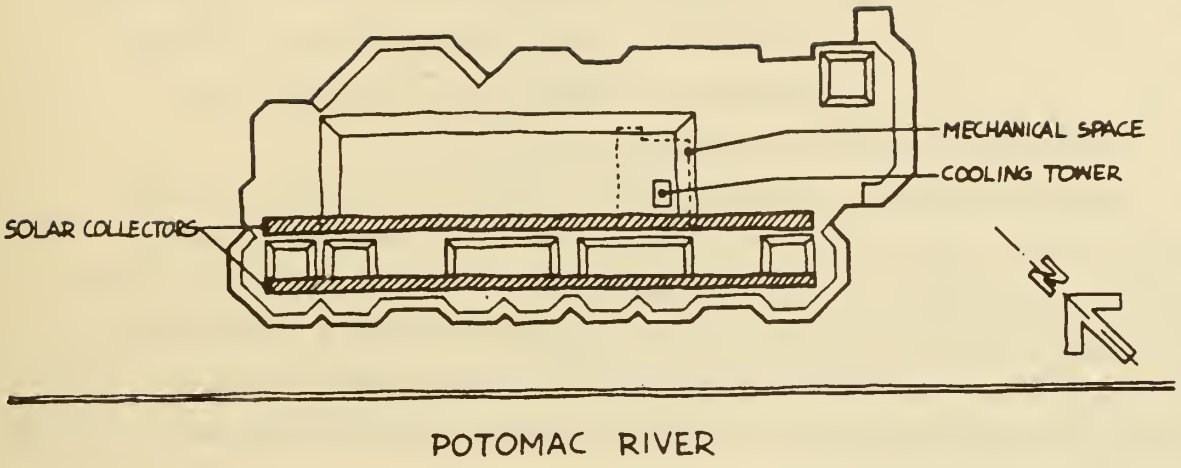


Figure A-5
Hogate's Site Plan

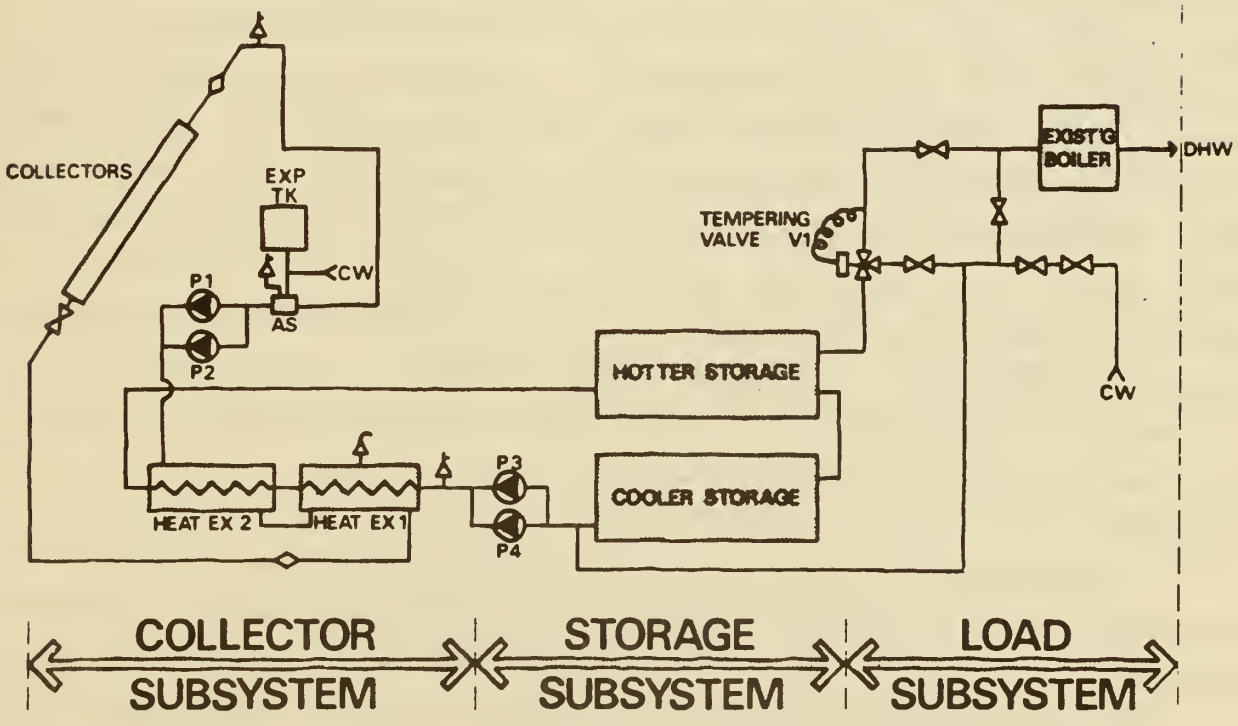


Figure A-6
Hogate's Schematic

- NEW OR RETROFIT: Retrofit
- PERFORMANCE EVALUATION INSTRUMENTATION: Yes
- SITE-SPECIFIC FEATURES: Two heat exchangers in series

Solar energy is used to preheat process water for this 600 seat restaurant on the north bank of the Potomac River in Washington, D.C. The solar energy system was retrofitted to the building during the summer and autumn of 1977.

The system utilizes 300 Sunworks collectors with a total effective aperture area of 5,840 square feet. The collectors face 45° west of South at a tilt angle of 55° from the horizontal because of building constraints. The collectors are mounted in two rows, each two collectors high on a steel I-beam support structure that runs parallel to the sloped lines of the two existing mansard roofs.

All collectors are piped in parallel, and balancing valves are used for flow balancing. A propylene glycol and water mixture is used in the collectors, and the fluid is pumped through two heat exchangers in series. On the load side of the heat exchangers, duplex pumps circulate water from the storage tanks and back to the heat exchangers. On demand for hot water in the restaurant, preheated water flows from the tanks to a gas-fired boiler as cold water make-up is fed to the tanks. All the pumps, heat exchangers, and controls are located in a mechanical equipment room in the penthouse at the same level as the collectors. Two 5,000 gallon pressurized storage tanks are located two floors below the equipment room in a parking garage. All system piping is copper, insulated with fiberglass. A canvas jacket is used on interior piping and an aluminum jacket is used on exterior piping.

The system has been fully instrumented for performance evaluation and has been integrated into the National Solar Data Network.

- ARATEX SERVICES INDUSTRIAL LAUNDRY (SEE FIGURE A-7 AND A-8)

The following is a brief summary of the Aratex solar installation. Highlights of this site include:

- o COLLECTOR TYPE: Flat plate, Liquid
- o FREEZE PROTECTION: Draindown
- o APPLICATION: Laundry process water heating
- o STORAGE TYPE: Exterior tank
- o NEW OR RETROFIT: Retrofit
- o INSTRUMENTED FOR PERFORMANCE EVALUATION: Yes
- o SITE SPECIFIC FEATURES: Wastewater heat recovery unit, hot water holding tank that is steam preheated and steam condensate heated.

The solar energy is used to heat process water in a large commercial laundering plant in Fresno, California. The solar system was retrofitted to the building during the winter and spring of 1977.

The system utilizes 140 Ying, flat plate, lexan glazed collectors which provide an effective aperture area of 6,350 square feet. The collectors are mounted in 24 rows on the flat roof of the building.

All collectors are connected in parallel with hoses and clamps, to the copper manifold. The water is pumped between the collectors and the atmospherically vented storage tank. The 12,500 gallon insulated fiberglass storage tank is located above ground on the concrete floor of a covered area of the building which is open to the outside.

All of the pumps for the system are located near the storage tank. All solar energy system piping is copper. All exterior piping is insulated with fiberglass, covered by an aluminum jacket.

The solar energy system is used in conjunction with a heat recovery system. Softened cold water is first pumped through a heat exchanger which recovers heat from the laundry wastewater. The water then flows into the solar storage tank and circulates through the collectors. It is then pumped through another heat exchanger which boosts the water temperature to the required temperature of 170°F. Steam from the building heating boiler is used as the auxiliary energy source.

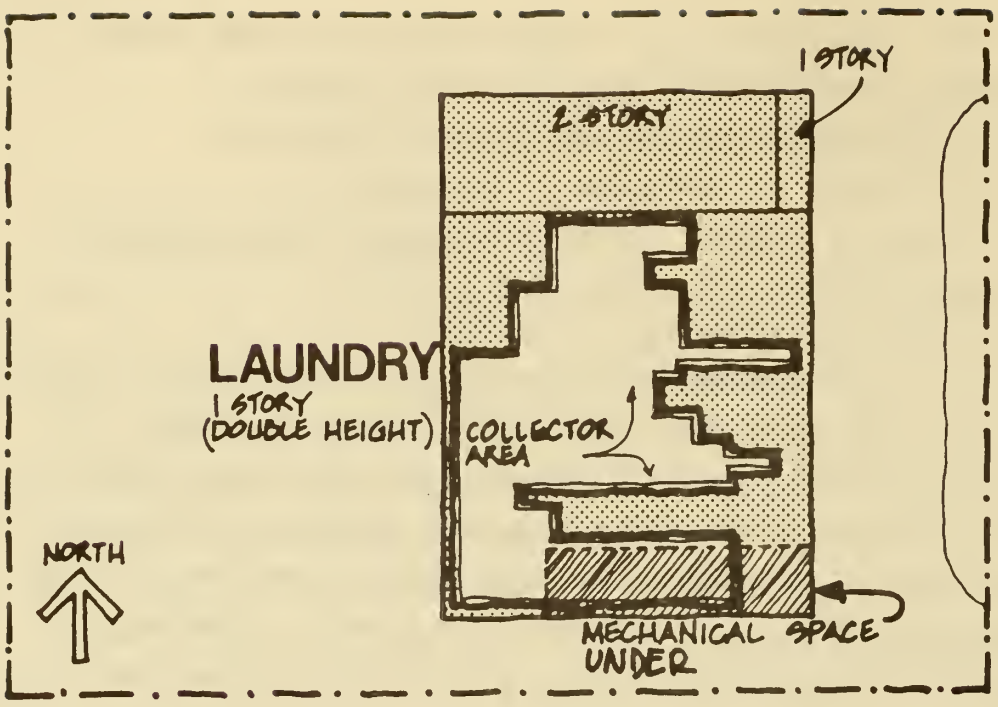


Figure A-7
Aratex Site Plan

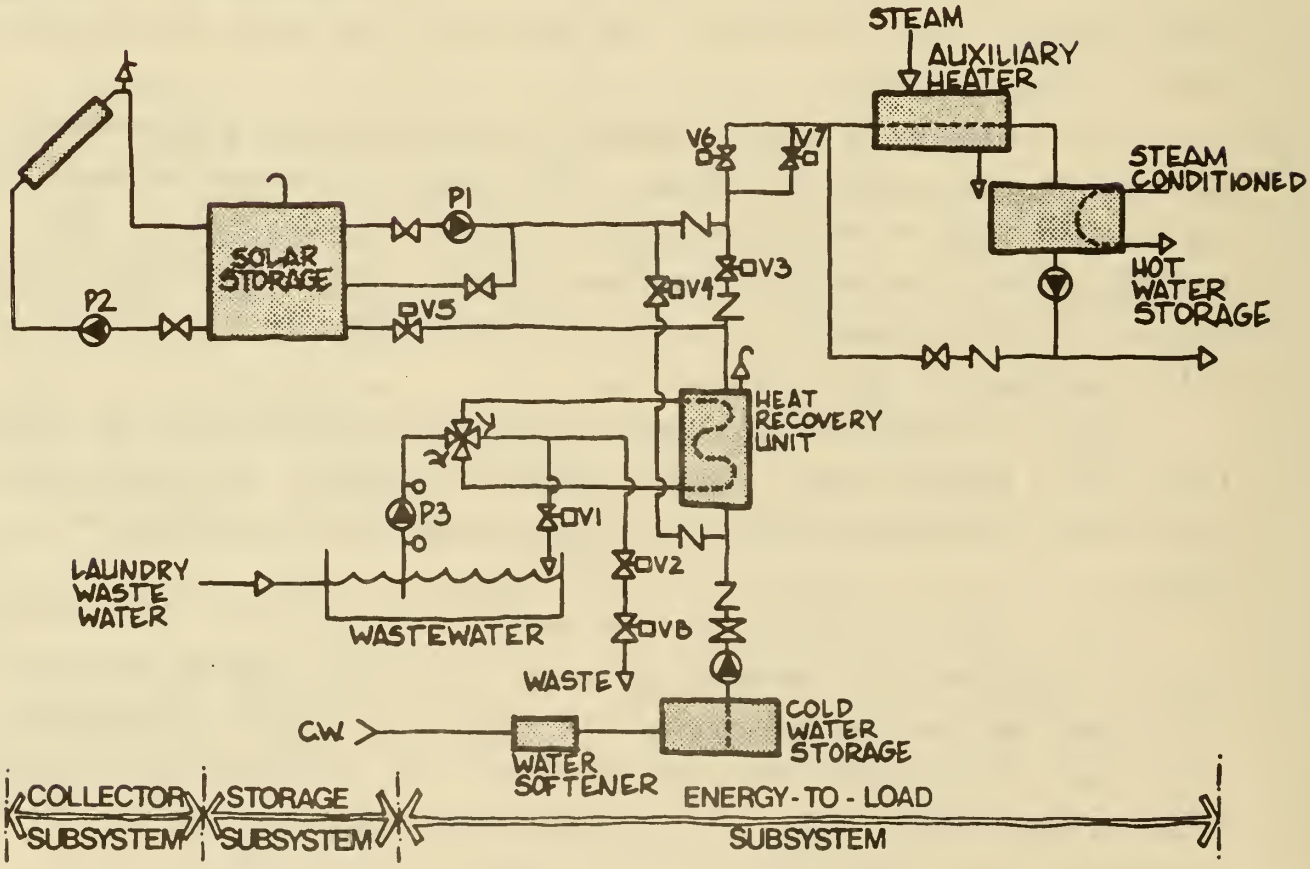


Figure A-8
Aratex Schematic

Hot water is stored in a 4,000 gallon holding tank to which an immersed heat exchanger adds heat from the steam condensate.

The solar system has been fully instrumented for data acquisition and is included in the National Solar Data Network.

C. SPACE HEATING

- TERRELL E. MOSELEY OFFICE BUILDING (SEE FIGURES A-9 AND A-10)
  - COLLECTOR TYPE: Liquid, Flat plate
  - FREEZE PROTECTION: Drain down
  - APPLICATION: Heating, Hot water
  - STORAGE: Interior tank
  - NEW OR RETROFIT: Retrofit
  - PERFORMANCE EVALUATION INSTRUMENTATION: Yes
  - SITE-SPECIFIC FEATURES: Water source heat pump, Site fabricated collectors

The solar energy system for a one story office building in Lynchburg, Virginia, preheats domestic hot water and heat 1780 square feet of occupied space. The building owner, Terrell E. Moseley, Inc., designed and installed the solar system as a retrofit.

The 376 square foot collector array was fabricated by the owner in a single bank on the roof of the adjoining warehouse to the solar conditioned offices. The aluminum absorber plate, painted flat black, is mechanically fastened to a copper tubing manifold. A thermally conductive mastic is used to improve heat transfer properties between the absorber plate and the tubing. The collector back is insulated with a four inch thick fiberglass batt. The collector array is mounted on a wooden framing. A steel angle and pipe structure supports the collector array at a 50 degree tilt to the horizontal.

The collectors are piped in parallel in reverse return and are drained down for freeze protection.

A 2000 gallon steel storage tank, covered with fiberglass insulation, is located in the warehouse adjoining the solar-conditioned offices. The tank is kept partially full so that water may expand without the need for a separate expansion tank.

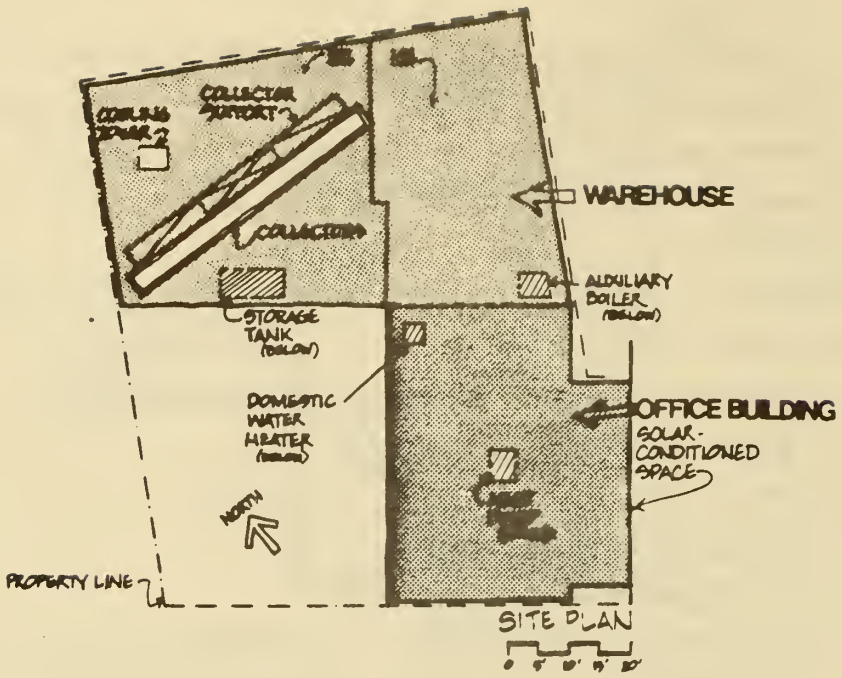


Figure A-9
Moseley Site Plan

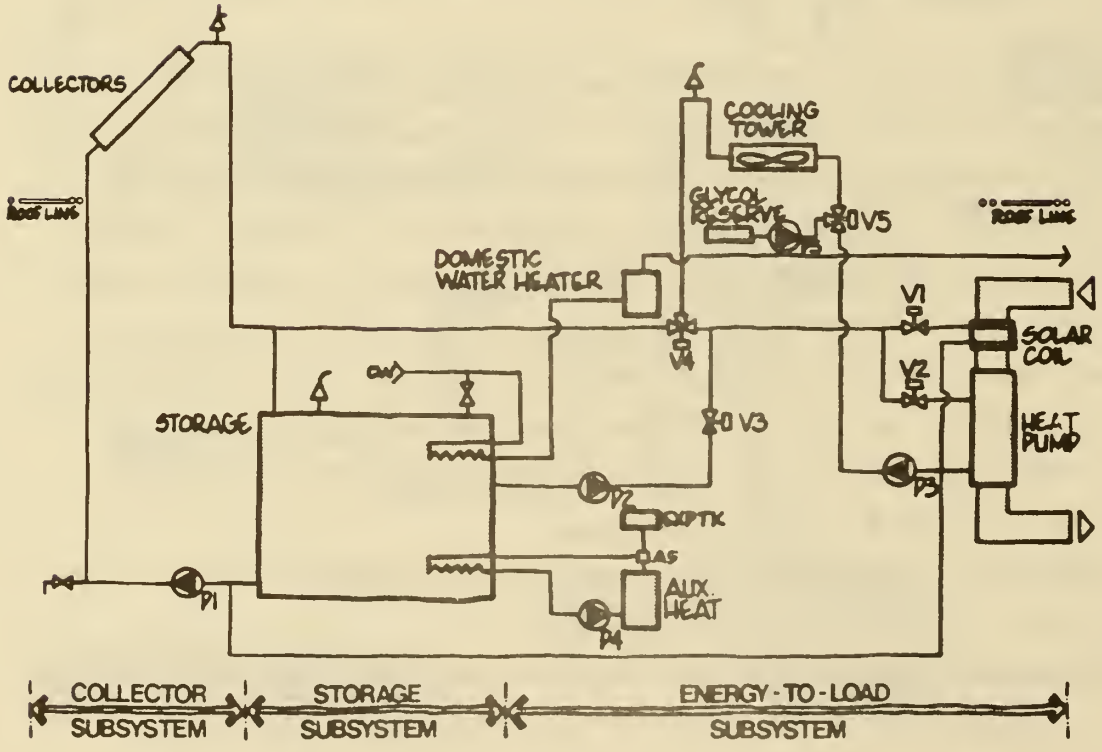


Figure A-10
Moseley Schematic

Service hot water is preheated by an immersed coil in the storage tank and is passed through an electric water heater.

Space heating is provided by pumping water from the storage tank through a duct heating coil and/or a water source heat pump. Valves direct the flow through the coil and heat pump and are dependent on the storage water temperature. To maintain a minimum temperature of 55°F in the storage tank, hot water from an auxiliary gas-fired boiler is circulated through an immersed coil in the storage tank.

Space cooling is provided by the water source heat pump, which is located in a closet in the solar conditioned space. A closed-circuit, dry cooling tower on the warehouse roof is used for heat rejection.

The system has been fully instrumented for performance evaluation since September 1977 and integrated into the National Solar Data Network.

- BLAKEDALE PROFESSIONAL BUILDING (SEE FIGURES A-11 AND A-12)

The following is a brief summary of the Blakedale Professional Center solar installation. Major features of this system include:

- o COLLECTOR: Liquid, Flat plate*
- o FREEZE PROTECTION: Drain down
- o APPLICATION: Heating, Hot water
- o STORAGE: Liquid, Exterior, Buried
- o NEW OR RETROFIT: New
- o PERFORMANCE EVALUATION INSTRUMENTATION: Yes
- o SITE-SPECIFIC FEATURES: Reflectors, Heat pump

Space heating and domestic hot water heating is provided by a solar energy system utilizing 924 square feet of liquid flat

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*Note: The building and solar system were designed and construction was begun early in 1975, before the first Program Opportunity Notice was released. The original design employed collectors having aluminum absorber plates, and freeze protection was provided by means of a nitrogen blow-down system. These original units were replaced during 1977 with copper collectors because of glazing fractures and the nitrogen system was replaced with an atmospheric drain-down.

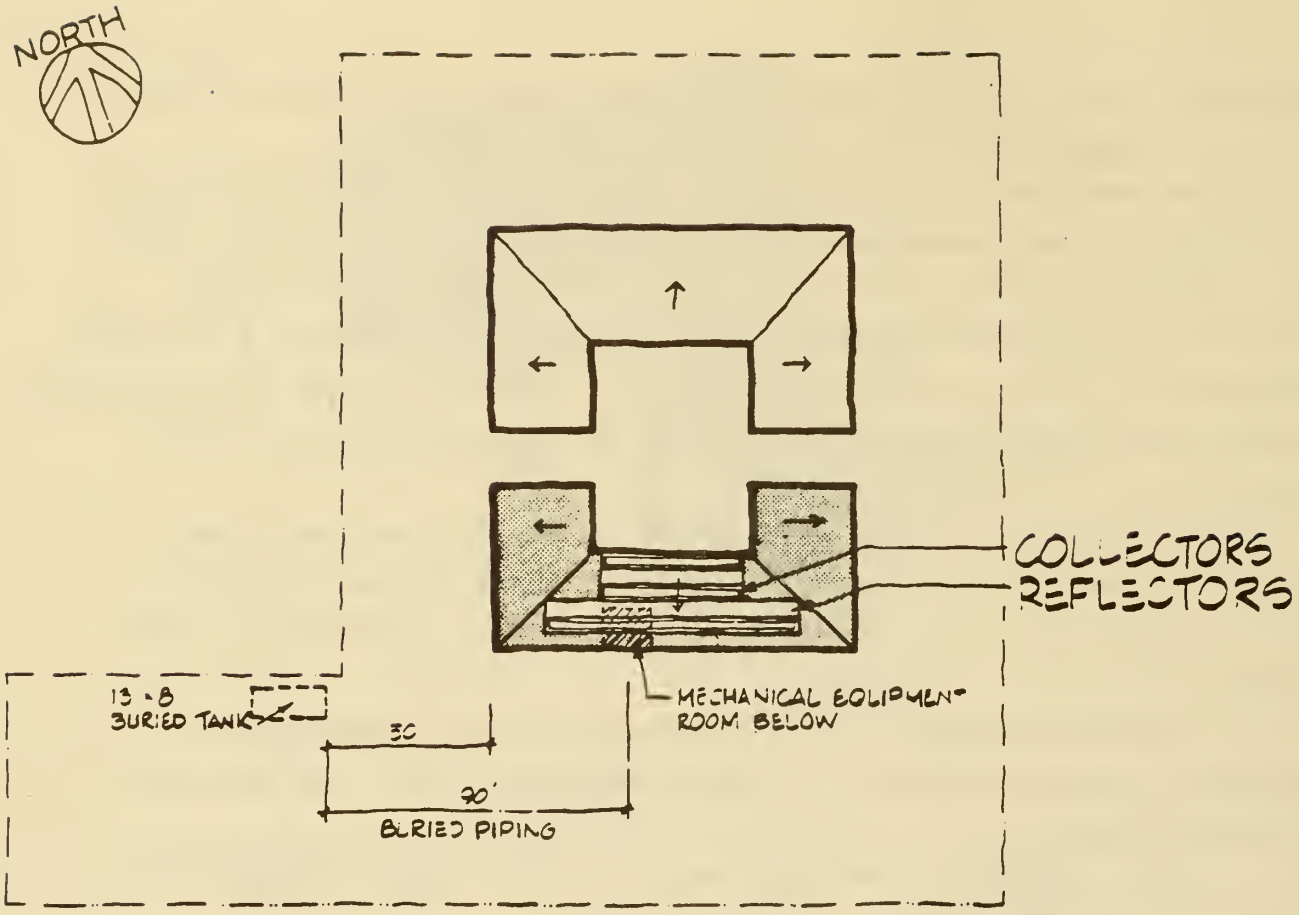

Figure A-11
Blakedale Site Plan

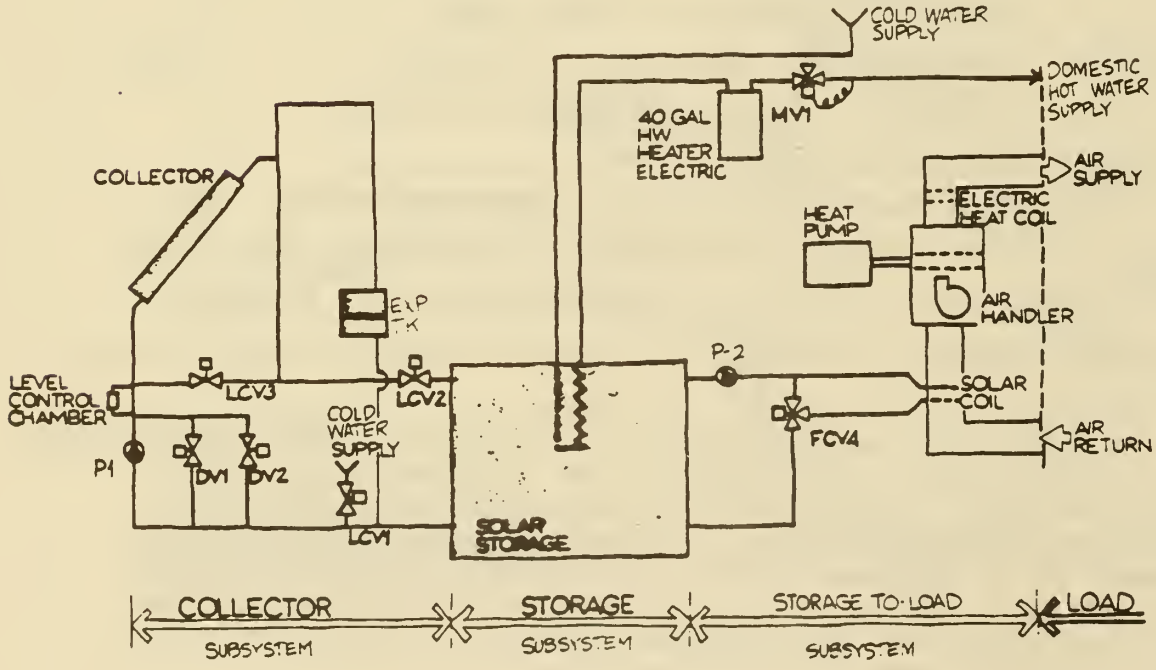

Figure A-12
Blakedale Schematic

plate collectors for a 10,000 square foot, one story office building, Blakedale Professional Center, in Greenwood, South Carolina. The system was installed concurrent with building construction and serves 4,400 square feet of the building.

The collectors are roof-mounted in three banks on wooden, sawtooth type supports with aluminized mylar reflectors on the back of the supports. The collectors are double-glazed with tempered glass and have copper absorber plates and a non-selective black coating. A drain down system protects the collectors from freezing.

A 5,000 gallon steel storage tank, covered with polyurethane insulation, is buried underground approximately 50 feet from the building.

The heat from the tank is transferred to the space through a coil in the warm air duct. A heat pump is operated downstream of the solar heating coil in the duct to provide auxiliary heat. An electric resistance coil in the duct is also furnished for additional heat when required. Service hot water is heated by a single-wall tube bundle heat exchanger immersed in the storage tank and is backed up by a 40 gallon electric water heater.

No heat exchangers are utilized between the collector, the storage tank and the solar heating coil in the duct. The piping for the system is galvanized steel, and the collector fluid is treated with a corrosion inhibitor.

The system has been fully instrumented for performance evaluation and integrated into the National Solar Data Network.

- SCATTERGOOD SCHOOL RECREATION CENTER (SEE FIGURES A-13 and A-14)

The following is a brief summary of the Scattergood School Recreation Center solar installation. Major features of this system include:

- o COLLECTOR TYPE: Air, Flat plate
- o FREEZE PROTECTION: Drain-down
- o APPLICATION: Heating, Hot water
- o STORAGE TYPE: Pebble bed, Partially buried

- NEW OR RETROFIT: New
- PERFORMANCE EVALUATION INSTRUMENTATION: Yes
- SITE-SPECIFIC FEATURES: Grain dryer silo

The solar energy system, utilizing 2240 square feet of collectors, supplies a portion of the space heating and domestic hot water requirements for the 6900 square feet gymnasium and 1966 square feet of locker rooms at the Scattergood School, West Branch, Iowa. The solar energy system was installed during building construction. A 6000 bushel grain dryer, installed later, may also use the solar system during its operation.

The four-tier collector array, tilted at 50°, consists of 128 double glazed collectors that use air as the heat transfer fluid. The array is attached to the southward facing gymnasium wall on a shed type structure. The area between the collector array and the gymnasium wall, which is enclosed but unconditioned, houses the storage tank, air handling equipment, ductwork, and other solar system components.

The storage tank is a partially buried 65 ton pebble bed tank. It is insulated with two inches of fiberglass. The pebbles are washed river gravel, one to three inches in diameter.

Space heating is provided from either the collector array or the storage tank and is distributed through the duct distribution system in the gymnasium. The ductwork in the unconditioned space is covered with 1 inch thick, foil-faced, fiberglass insulation.

Domestic hot water is preheated by a cross-flow air to water heat exchanger located in the warm air supply duct and is stored in two 120 gallon, glass-lined, storage tanks. Manual dampers are provided so that the solar system is able to preheat the domestic hot water without heating the gymnasium during summer.

The auxiliary energy system consists of two propane-fired unit heaters in the gymnasium, a down-flow propane-fired furnace in the locker room, and a 52 gallon quick-recovery electric water heater.

The solar energy system has been operational since May 1977. It has been fully instrumented for performance evaluation and integrated into the National Solar Data Network.

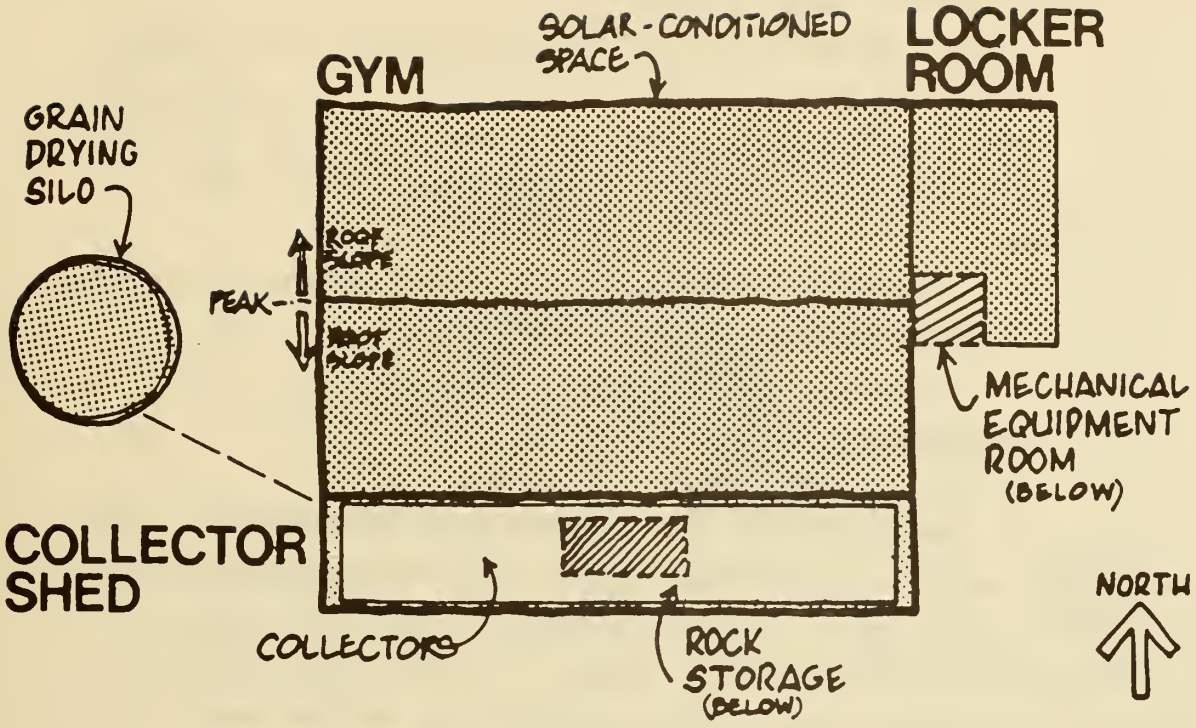

Figure A-13
Scattergood Site Plan

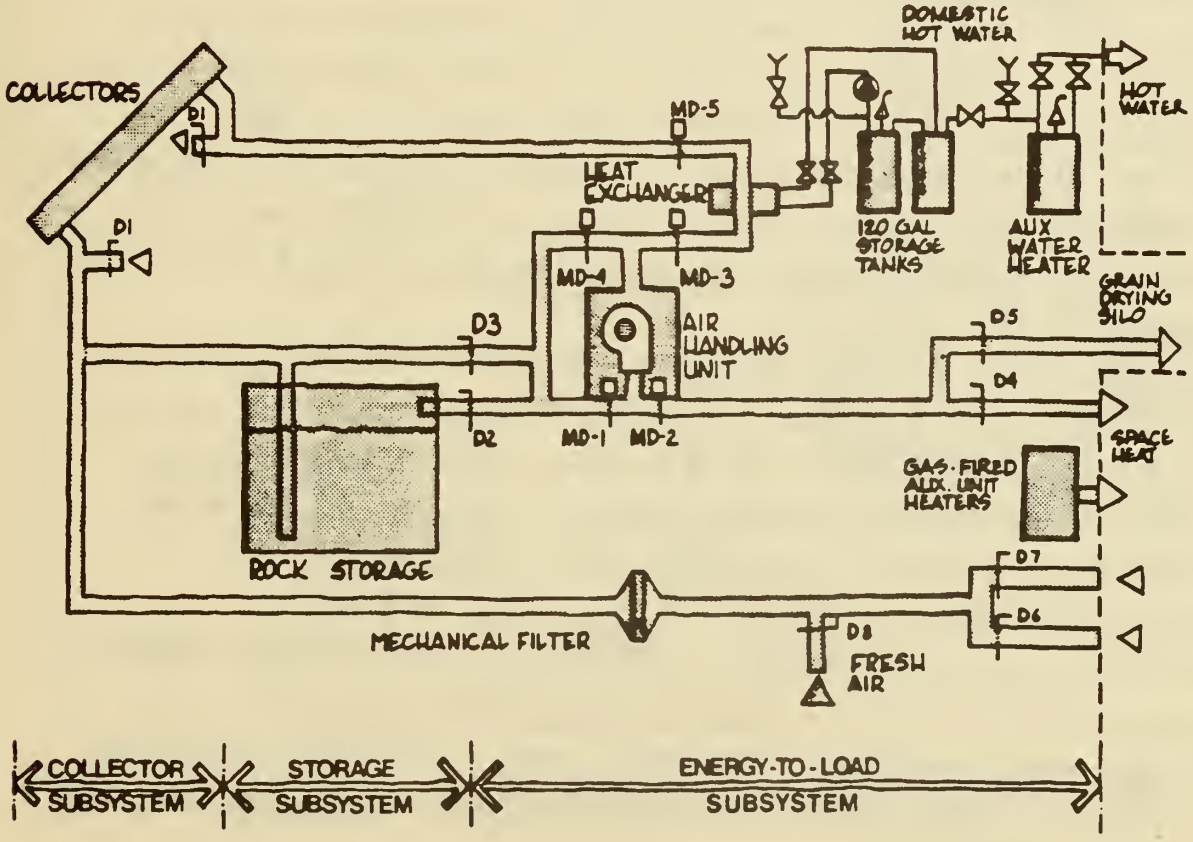

Figure A-14
Scattergood Schematic

D. SPACE HEATING AND COOLING

- RADIAN CORPORATION OFFICE BUILDING (SEE FIGURES A-15 AND A-16)

The following is a brief summary of the Radian Corporation Office Building solar installation. Highlights of this site include:

- o COLLECTOR TYPE: Fresnel lens, Liquid, Tracking
- o FREEZE PROTECTION: Antifreeze
- o APPLICATION: Heating, Cooling
- o STORAGE TYPE: Exterior Tank
- o NEW OR RETORFIT: Retrofit
- o INSTRUMENTED FOR PERFORMANCE EVALUATION: Yes

The solar energy system heats and cools approximately 800 square feet of office and laboratory area in this two story, modern office building in Austin, Texas. Though intended to be installed as the building was constructed, the system was actually installed when the building was essentially complete and, thus, must be considered a retrofit installation.

The system utilizes 36 Northrup concentrating collectors which provide an effective aperture area of 350 square feet. The collectors are ganged in two banks on the flat roof of the building. An aluminum angle support structure tilts the collectors toward the south and the collectors track the sun from east to west through the day. A tracking mechanism is provided for each of the two banks of collectors.

The collectors in each bank are connected in parallel with hoses and clamps to the copper manifolds. A water/glycol mixture is pumped from the collectors to a counter flow heat exchanger between the collectors and storage tank. The 1500 gallon insulated, fiberglass storage tank is located above ground on a concrete pad near the building.

All but one of the pumps for the system are located outside the building near the tank and are covered with individual galvanized sheet metal housing. The other pump is located near the chiller. All exterior piping is insulated with fiberglass covered by an aluminum jacket.

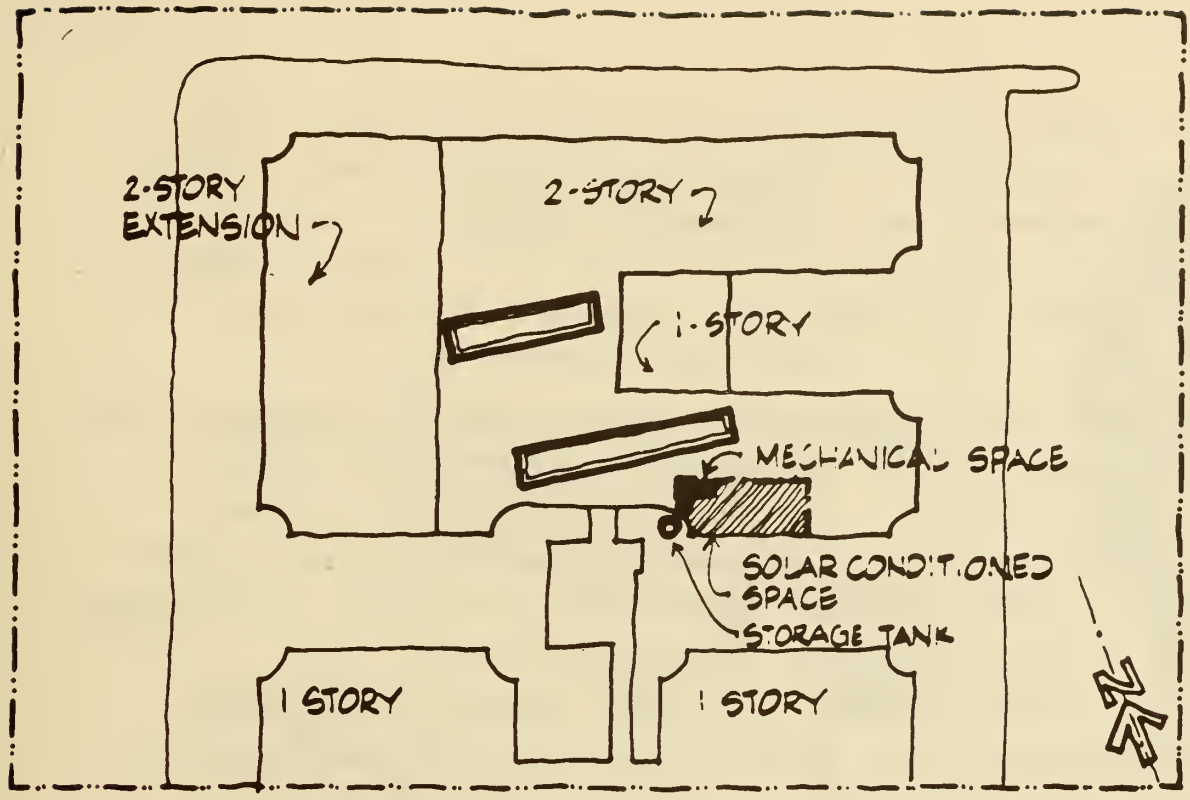

Figure A-15
Radian Site Plan

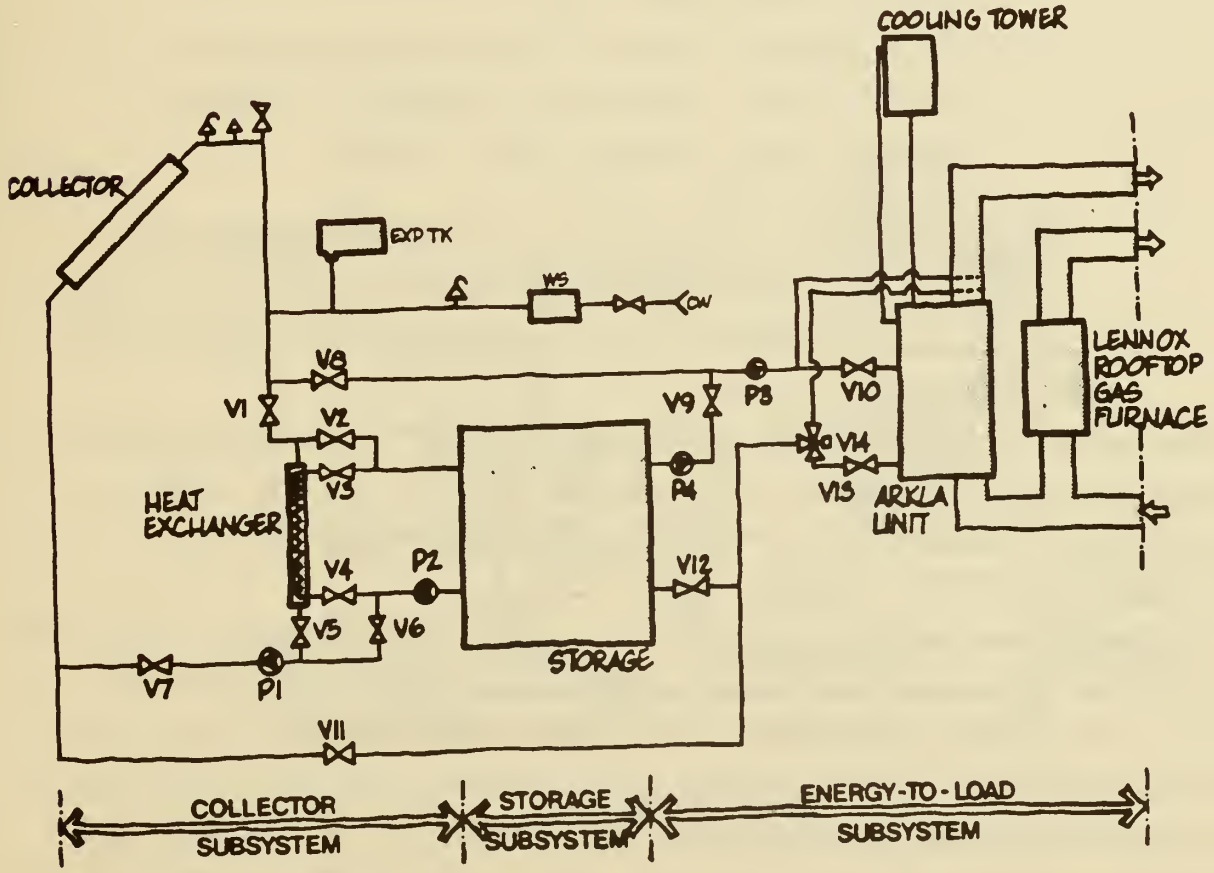

Figure A-16
Radian Schematic

The cooling equipment for the system is an Arkla three ton packaged absorption air-cooler located on the second floor of the building and a cooling tower on the roof. A separate heating coil, through which solar heated water from the storage tank is circulated, is provided in the Arkla unit for space heating.

Auxiliary heating and cooling to the three solar conditioned rooms is provided through a completely separate duct system.

The solar system has been fully instrumented for data acquisition and is included in the National Solar Data Network.

- REEDY CREEK UTILITIES OFFICE BUILDING (SEE FIGURES A-17 and A-18)

The following is a brief summary of the Reedy Creek Utilities Co., Inc., Office Building solar installation. Highlights of this site include:

- o COLLECTOR TYPE: Fixed, horizontal, parabolic trough reflectors with tracking absorbers
- o FREEZE PROTECTION: None
- o APPLICATION: Heating, Cooling, Hot water
- o STORAGE TYPE: Exterior hot water, Exterior chilled water, Above-ground tanks
- o NEW OR RETROFIT: New
- o PERFORMANCE EVALUATION INSTRUMENTATION: Yes
- o SITE-SPECIFIC FEATURES: Chilled water storage tank, Modular reflectors replacing conventional roofing

The solar energy system heats, cools, and provides domestic hot water for approximately 5,625 square feet of office area in this two-story, modern office building in Walt Disney World, Florida.

The solar collectors consist of 16 parabolic trough reflectors with tracking absorber tubes and provide an effective aperture area of 3,840 square feet. The reflectors, which are 32 feet long and have a chord width of 7.5 feet, are constructed of aluminum with polyisocyanurate foam insulation. Glass mirror strips are glued to the reflectors with mastic. The reflectors are mounted

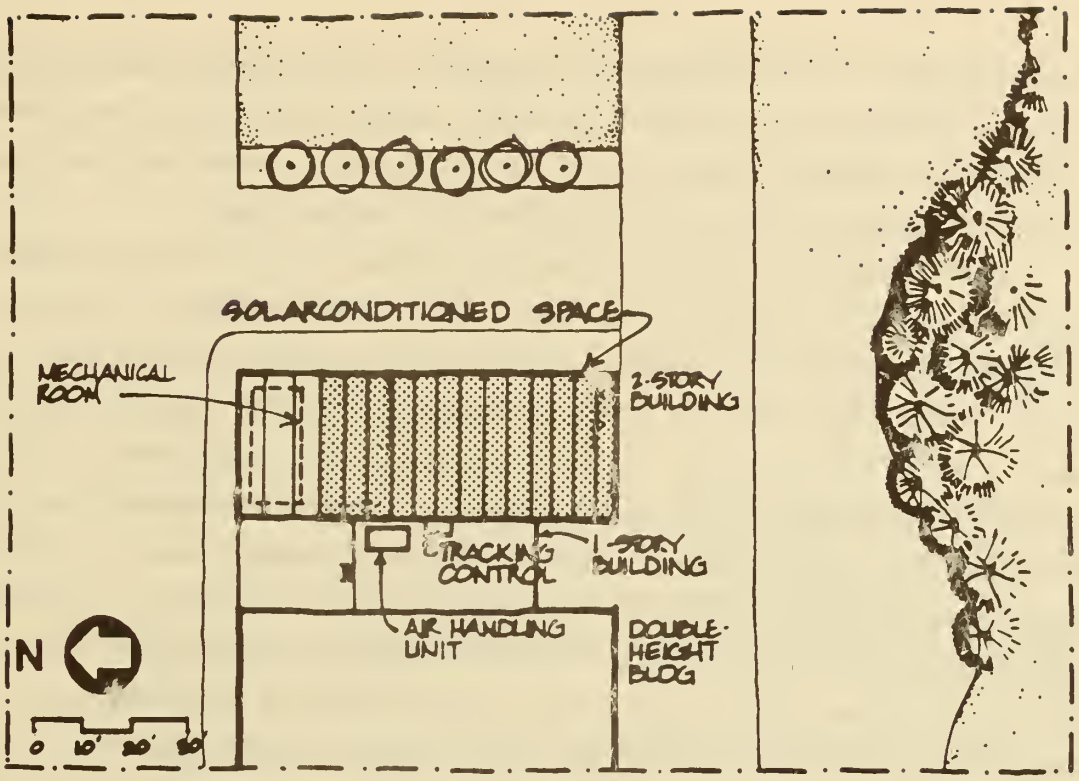

Figure A-17
Reedy Creek Site Plan

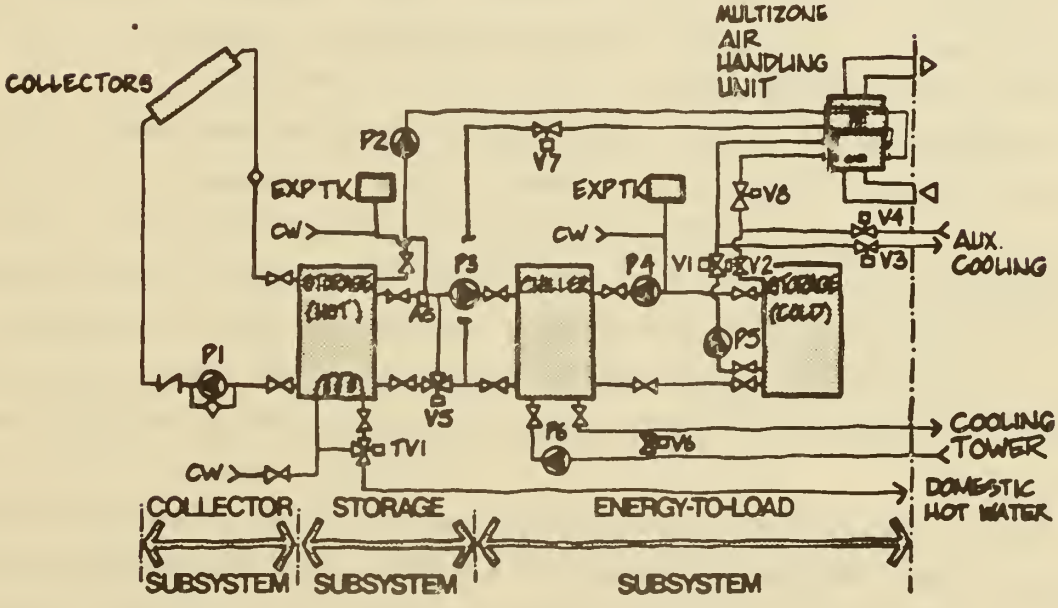

Figure A-18
Reedy Creek Schematic

horizontally in an east-west direction on saddles and replace the conventional roof. Stiffeners were attached to the reflectors to support lights, ducts, and sprinklers. These reflectors were installed using modular construction techniques.

The absorbers are 36-foot-long mounted above the reflectors. Copper absorber tubing is mechanically attached to grooved aluminum absorber plates. These plates are coated with black epoxy paint. The glazing is a single sheet of milky-white selective glass. Polyisocyanurate foam insulates the absorber tubing and a painted aluminum cover protects the absorber assembly. The absorbers are supported at both ends by rocker arms and are interconnected horizontally by adjustable tie bars. To keep the absorbers in focus, an electric-eye sensor and motor drive a linear activator that moves the absorbers in a north-south direction. Overheat protection is provided by defocusing the absorbers. There is no freeze protection system.

Solar energy is transferred from the absorbers to a hot water storage tank by water. The tank, which is 20 feet high and 9 feet in diameter, holds 10,000 gallons, and is located on a concrete slab adjacent to the solar conditioned building. The tank is covered overhead by the roof. The tank is insulated with 5 inches of fiberglass insulation that is covered with canvas and insulating cement.

Space heating is provided by circulating hot water from the hot water storage tank to a duct-coil heat exchanger in an air-handling unit. The air-handling unit is located on the roof of a building adjoining the solar conditioned offices. Hot water is provided by circulating city water through a coil in the hot water storage tank. A thermostatic mixing valve mixes cold and hot water so that the temperature of the hot water supply never exceeds 140°F.

Space cooling is provided by chilling water in a 25 ton absorption unit which is operated by hot water from the hot water storage tank. The chilled water is stored in a 10,000 gallon chilled water storage tank which measures 20 feet high and 9 feet in diameter. It is covered with 4 inches of fiberglass insulation,

canvas, and insulating cement. Chilled water from this storage tank is piped through a duct-coil heat exchanger in the air-handling unit. The absorption chiller and chilled water storage tank are located outside, next to the hot water storage tank.

The auxiliary energy system provides only chilled water for space cooling requirements. The chilled water is produced by the Central Energy Plant for Disney World which adjoins the solar conditioned building. There is no auxiliary system for space or domestic water heating.

The solar energy system has been fully operational since November 1977. It has been instrumented for performance evaluation and integrated into the National Solar Data Network.

- TRINITY UNIVERSITY CENTRAL POWER PLANT (SEE FIGURES A-19 AND A-20)

The following is a brief summary of the Trinity University Power Plant #2 solar installation. Highlights of this site include:

- o COLLECTOR TYPE: Fresnel lens, Liquid, Tracking
- o FREEZE PROTECTION: Warm water circulation
- o APPLICATION: Heating, Cooling, Hot water
- o STORAGE TYPE: Liquid, Buried exterior tanks
- o NEW OR RETROFIT: Retrofit
- o PERFORMANCE EVALUATION INSTRUMENTATION: Yes
- o SITE SPECIFIC FEATURES: Solar system can operate in four modes and provides space conditioning for seven buildings.

The Trinity University solar energy system in San Antonio, Texas is used for space heating, cooling and hot water for an athletic complex and six dormitories which house about 500 students. The total floor space conditioned by the solar system is about 285,000 square feet.

The 1608 Northrup concentrating collectors, which are mounted in two collector arrays of 632 and 976 collectors, respectively, face south at a 30° angle to the horizontal on the two flat roofs of the athletic complex. The overall collector area is about 16,080 square feet, while the effective aperture

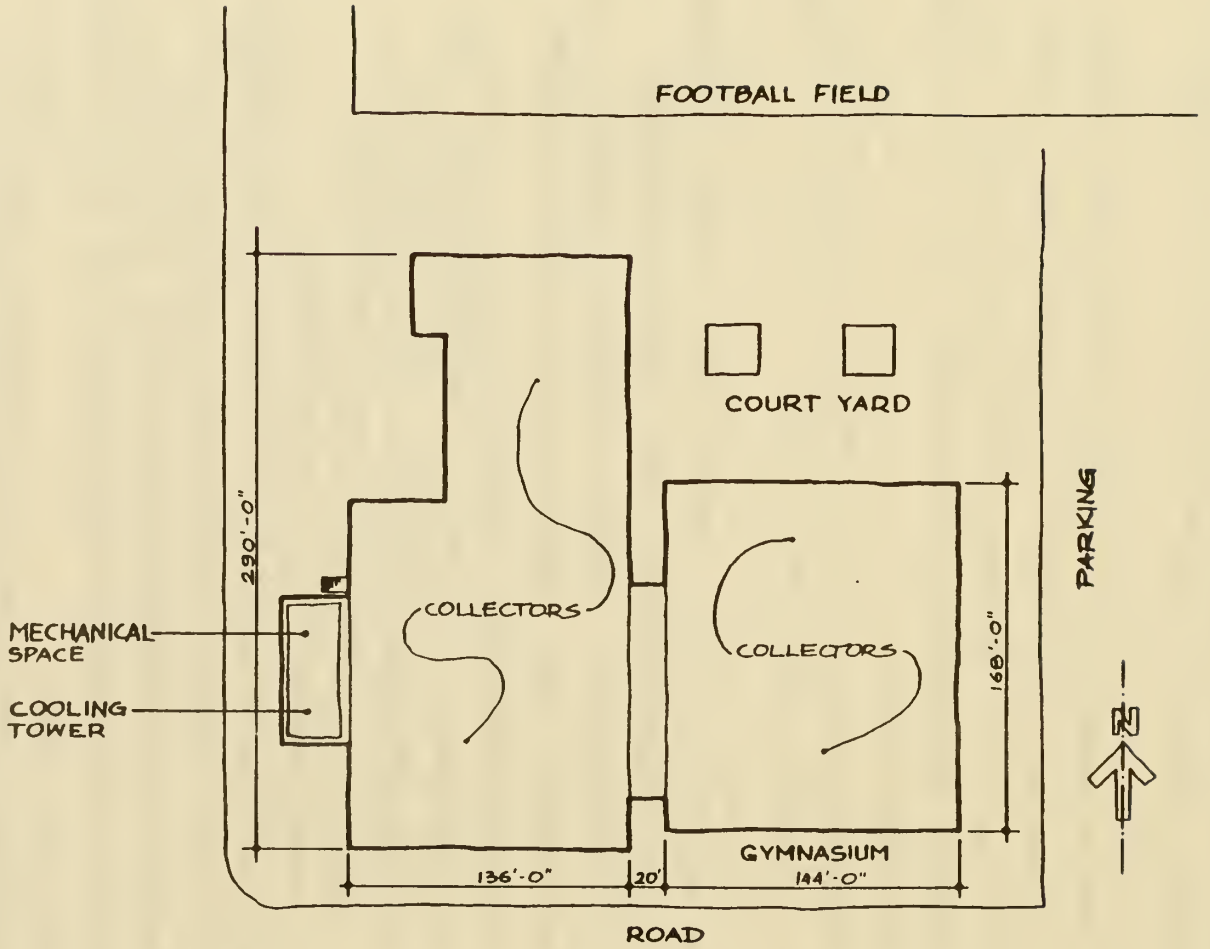

FIGURE A-19 - Trinity Site Plan

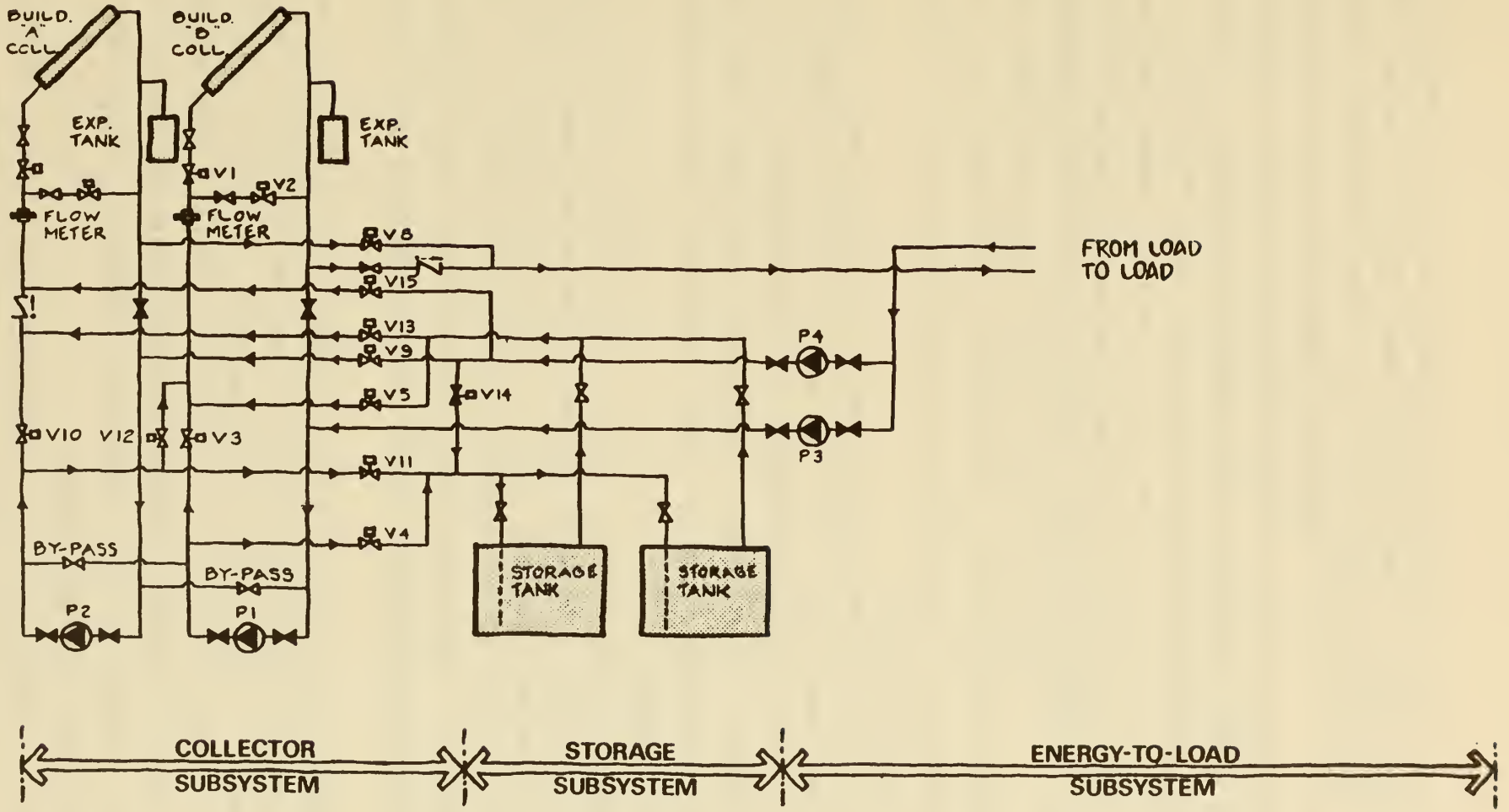

FIGURE A-20 - Trinity Schematic

area is about 15,633 square feet. Water from two buried insulated storage tanks may be circulated through the collector arrays in either series or parallel circuit. The collectors, which were prefabricated in 16-unit modules, are supported by an unpainted, galvanized steel structure. The collectors in each of the 104 modules are piped in reverse return, and each module has a separate drive motor to focus the collectors toward the sun. The absorber manifold piping is copper; the supply and return lines are steel. A dialectric union separates the copper and steel lines.

Overheat protection is provided by defocusing the collectors; freeze protection is provided by circulating warm storage water through the collectors.

Two 20,000 gallon storage tanks are buried about 50 feet north of the power plant building and are used for thermal storage. The power plant building connects with the western wall of the athletic center. These tanks are piped in parallel, and either tank may be isolated from the solar system so that the remaining tank may be heated faster.

Space heating and cooling for the athletic center is provided by a recirculating four-pipe system. The solar energy system preheats the space heating water in one heat exchanger while high temperature boiler water provides additional heating in a second heat exchanger. Space cooling is provided by chilling water with a solar-powered absorption chiller or an electric centrifugal chiller.

Domestic hot water for the athletic center and for two of the six dormitories is supplied by a buried, recirculating two-pipe system. A 3,000 gallon storage tank is integrated into the system to provide additional capacity to satisfy peak demands. Domestic water is passed through a heat exchanger within the solar system and through an auxiliary heat exchanger in the high temperature boiler water system.

The six domitories can be supplied with either space heating or cooling by a buried, recirculating two-pipe system. A change-over valve, located in the power plant room, is adjusted manually.

A solar-powered 352 ton absorption chiller is used for space cooling and is located in the power plant room. A three-cell ceramic cooling tower, mounted on the flat roof of the power plant, rejects heat from the condenser water.

The auxiliary energy system consists of a 405 horsepower natural gas boiler, a 623 ton electric centrifugal chiller, and the three-cell cooling tower. The boiler and chiller are located in the power plant room.

The solar energy system has been fully instrumented for thermal performance and integrated into the National Solar Data Network. The system has been working since June 1977.

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